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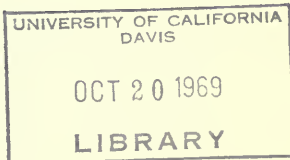
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BULLETIN No. 147-5

Ground Water Basin Protection Projects

SANITARY LANDFILL STUDIES

Appendix A: SUMMARY OF SELECTED PREVIOUS INVESTIGATIONS



JULY 1969

NORMAN B. LIVERMORE, JR.
Secretary for Resources
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JULY 1969

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Secretary for Resources
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Director
Department of Water Resources

FOREWORD

This appendix summarizes some of the work that has been conducted, primarily by other agencies, on the subject of sanitary landfills, with emphasis on studies in Southern California on the effect of landfills on ground water quality. The work is part of a larger Department study on landfills which is scheduled to expand in 1969 on a cooperative basis with local agencies. Information contained in this appendix will be basic to the continuing studies and is subject to modification as the studies develop. From the larger study will come the text for Bulletin No. 147-5, which is intended to answer some of the questions raised by previous investigations, particularly on formation and movement of gas and on landfill construction and operation techniques.

The bulletin is one of a series reporting the results of investigations authorized by Sections 12922 and 12923 of the State Water Code, known as the Porter-Dolwig Ground Water Basin Protection Law. This law provides that the Department of Water Resources shall study measures for the protection of the ground water basins of the State from water quality degradation.

In the investigation reported here, the Department received valuable assistance from a number of state and local agencies, private organizations, and individuals. Particular recognition is due the County Sanitation Districts of Los Angeles County; Messrs. Harold E. Bender, Albert Wise, and William Ellis of the Azusa Rock and Sand Company; Dr. William D. Bishop and Dr. Teng-chung Wu of Engineering-Science, Inc.; Professor Robert C. Merz of the University of Southern California; the City of Glendale, the City of Azusa; and the Los Angeles County Flood Control District. Their cooperation is gratefully acknowledged.

William R. Gianelli
William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
May 16, 1969

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ABSTRACT

Three principal techniques used for the disposal of refuse are incineration, open dumps, and sanitary landfills, of which landfills are the most useful and effective. This report not only gives information on landfills from investigations by the Department of Water Resources, but also summarizes the work of other investigators. / Decomposition of refuse in landfills results in the formation of gases. If sufficient water is available, these gas products may dissolve. Soluble organic and inorganic compounds may also be dissolved, forming leachate. / Instances of gas and leachate impairment of ground water are cited in this report, all of which indicate the necessity for control measures. They show that sanitary landfills should be designed as a system, with prime consideration given to site selection, materials to be deposited, construction and operation techniques, and use of the completed fill. / The report describes a system for classifying the physical characteristics of a site according to the degree of protection afforded receiving waters and for determining what type refuse could be disposed in each.

CHAPTER I. INTRODUCTION

more than 45,000 tons of refuse are produced daily in California at an average rate of about 4.5 pounds per capita per day^{(1)*}. Unless safe, practical, and efficient methods of waste disposal are established and practiced, there is a clear and present threat of impairment to the waters of the State.

The term refuse, as used in this report, refers to solid waste material resulting from normal community activity. At present, there are three main techniques for the disposal of refuse: incineration, disposal in open dumps, and disposal in landfills. Incineration may contribute heavily to air pollution and is prohibited in many areas. Open dumps are unsanitary sources of disagreeable odors and are breeding grounds for flies and rodents. Landfills are the most useful and effective.

Sanitary landfills, when properly operated, are clean and nuisance free, both during the filling operation and after completion. This is demonstrated by a number of landfills in the Los Angeles area, including the Palos Verdes Landfill (now partially covered by an arboretum), the City of Burbank Municipal Landfill, the Scholl Canyon Landfill of the County Sanitation Districts of Los Angeles County in Glendale, and the Mission Landfill in Sepulveda, all operating successfully in choice residential areas.

The potential pollution of ground waters by the products of landfill refuse decomposition is a problem faced by many large communities in California. Uncontrolled dumping still occurs. Many of these dump sites are in or tributary to areas overlying ground water basins. Ground water basins supply more than half the total water developed for use in California and are of prime importance to the economy of individuals, communities, and the State. They must be protected.

Objectives and Scope of the Investigation

Accordingly, the Department of Water Resources has undertaken a study with the objective of developing plans for protecting the ground water basins from possible impairment by refuse that has been disposed of in sanitary landfills. Before plans can be formulated, however, the production and movement of leachates and gases in various types of landfills must be thoroughly understood.

The objective of this appendix is to summarize some of the work that has been conducted to determine the effects of solid waste disposal on the quality of underlying ground water. This information, which will be available to agencies concerned with landfills, will be utilized in the continuing studies of landfills which will be carried on in cooperation with local agencies.

*References to the reports listed in Attachment 1 are designated in the text by Arabic numerals in parentheses.

Conduct of Investigation

A search was made of the technical publications. It was found that the studies reported by Engineering-Science, Inc., (15, 16, 17, 18, 19, 20) the Great Britain Ministry of Housing and Local Government, (3) and Professor Robert C. Merz of the University of Southern California (6, 7, 30) were particularly valuable.

In this investigation, data were collected by the Department at a number of landfills between 1962 and 1965.

Among the landfills studied, the Azusa Experimental Landfill, the Scholl Canyon Landfill, and the Valley Refuse Transfer Station, Inc., Waste Disposal Facility are the most important. Test facilities were also established at the Spadra Landfill site. Landfills for this study were selected on the basis of the geologic conditions underlying the sites and hydrologic features, including water application by precipitation and irrigation, and ground water presence and movement. The geologic conditions that are conducive to pollution are presence of highly pervious alluvial intervals from fill to ground water body and location of fills in canyons that are tributary to a ground water basin.

Azusa Experimental Landfill

The Azusa Experimental Landfill, a small test refuse landfill, is located in the northeast gravel pit of the Azusa Rock and Sand Company near Gladstone Street and Irwindale Avenue in Azusa, as shown in Figure 1. Also shown is the landfill operated by the Azusa Rock and Sand

Company. The San Gabriel River to the northwest and Little Dalton Wash to the southeast are the principal streams in the area. Drainage is generally southwest. Low relief and a southwesterly gradient of about 50 feet per mile are characteristic of the area. Elevations at the site range from 505 to 540 feet above sea level at the rim of the pit to about 320 feet above sea level at the lowest excavation.

This site was used jointly by the Department (to determine the effects of refuse decomposition products on underlying ground waters) and by Engineering Science, Inc., (to determine the movement of gases produced by decomposing refuse). Engineering-Science was under contract to the State Water Resources Control Board (formerly the State Water Quality Control Board).

The experimental landfill site was selected and refuse was placed in the spring of 1962. The refuse, amounting to 22,950 cubic yards (4,290 tons), consisted of newspapers, magazines, rubber tires, grass and shrubbery, glass bottles, plastics, porcelain and chinaware, tin cans, and a small amount of garbage. Refuse was placed in three 6-foot-thick layers, each separated by a silt layer 6 to 10 inches thick. The completed fill was covered with a 16-inch layer of silt.

To determine the effects of decomposition products on the underlying ground water, three wells were drilled by the Department. The effects on ground water quality caused by the experimental landfill and Azusa Rock and Sand landfill were observed by monitoring the test wells and various wells in the area for minerals and free CO₂ concentrations.

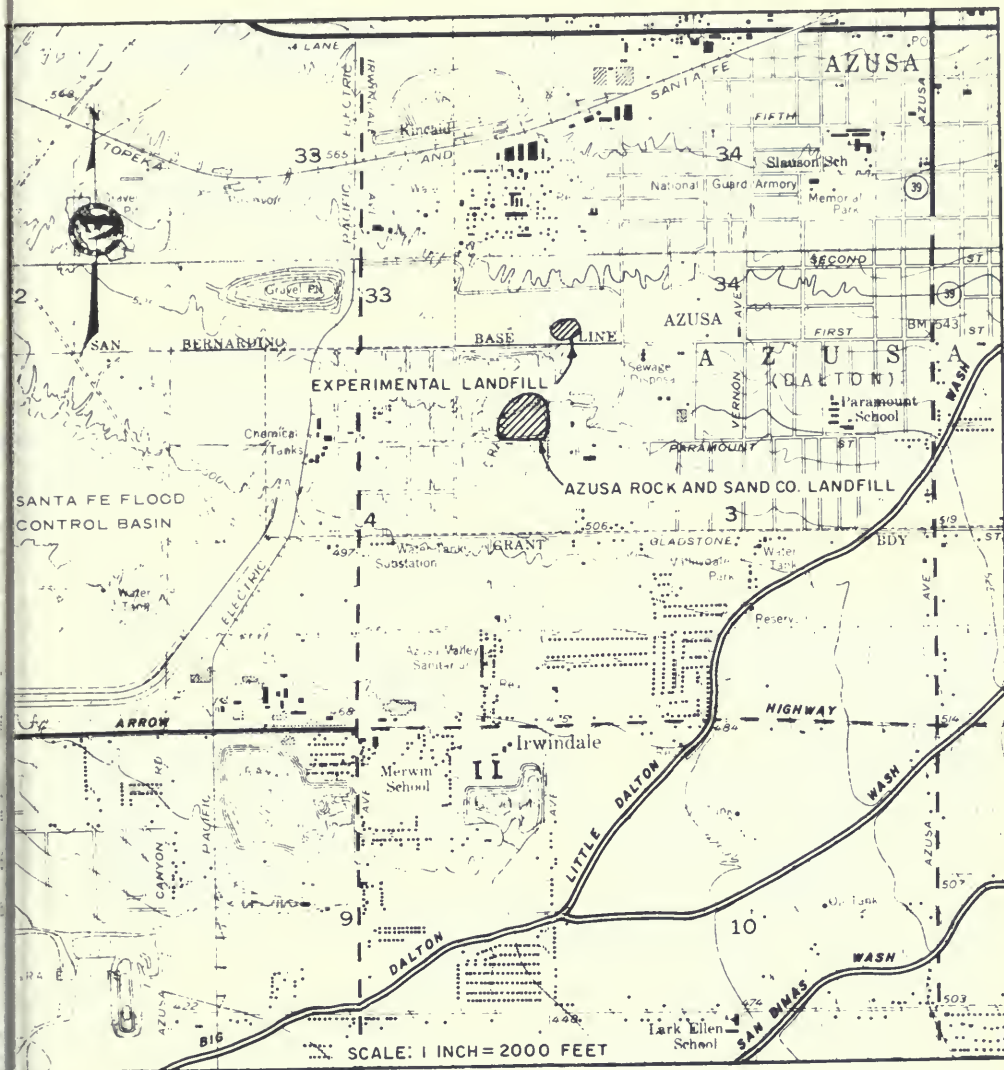


Figure 1. - AREA MAP - AZUSA EXPERIMENTAL LANDFILL

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

Scholl Canyon Landfill

The Scholl Canyon Landfill, Landfill No. 4 of the County Sanitation Districts of Los Angeles County, is in the San Rafael Hills at the end of Glenoaks Boulevard in Glendale, at the south-eastern end of the San Fernando Valley, as shown in Figure 2. The landfill site, with a total area of about 175 acres, occupies the upper reaches of Scholl Canyon and an unnamed tributary canyon entering from the north. The area has a typical steep-sloped mountain relief, with elevations ranging from 600 feet above sea level at the canyon mouth to about 1,900 feet at the highest level. Elevations at the landfill site, on the canyon floor, range from 950 to 1,400

feet above sea level. Drainage is generally westerly to Sycamore Canyon and then to the San Fernando Valley.

This site was selected for the study and evaluation of conditions accruing from irrigation (water application) of a refuse landfill.

Several wells were placed at the downstream edge of the landfill to allow interception, sampling, and analysis of leachate derived from the irrigated fill. Periodic mineral, sanitary, and heavy metal analyses were performed on samples from these wells over a period of 4 years.



Figure 2. - AREA MAP - SCHOLL CANYON LANDFILL

Valley Refuse Transfer Station, Inc.,
 Waste Disposal Facility (Mayflower
 Landfill)

Valley Refuse Transfer Station, Inc.,
 Waste Disposal Facility, hereafter re-
 ferred to as the Mayflower Landfill, is
 located on Live Oak Avenue and Peck Road in
 the City of Monrovia, as shown in Figure
 3. Extensive residential areas extend

north and west from the site, and an
 abandoned mobile home park is located
 partially on the completed fill. Num-
 erous gravel quarries are in the vicin-
 ity; a few of them are used for refuse
 disposal and several are used for spread-
 ing water to recharge the ground water
 basin. Principal streams in the area
 include the Rio Hondo and a tributary,
 Sawpit Wash. Drainage is generally
 southwest.

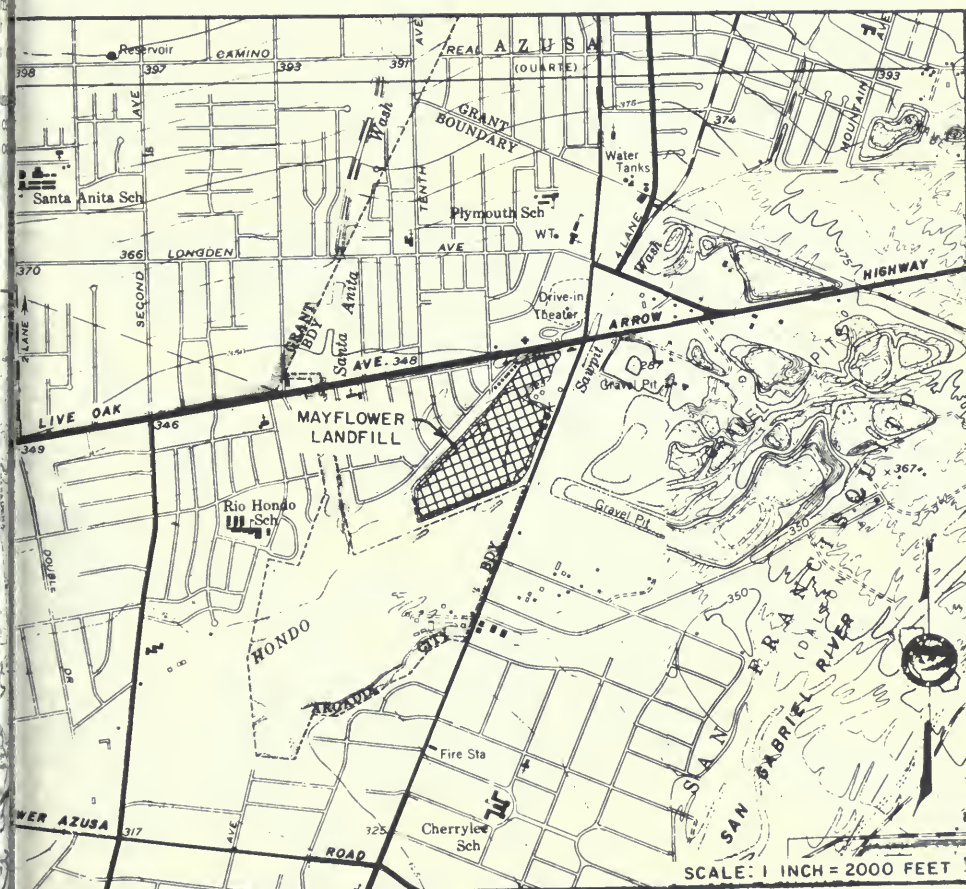


Figure 3 - AREA MAP - MAYFLOWER LANDFILL

This site was studied to determine the extent and severity of pollution brought about by inundation of the refuse due to spillage from water truck loading, street drainage, and ponded rainfall.

Three wells were drilled by the Department to determine the severity of ground water pollution. During the drilling, gas samples were collected at 20-foot intervals from the adjacent alluvium for analysis. Upon completion of the wells, ground water was sampled and analyzed for mineral and free CO₂ content. Selected wells throughout the area were also sampled and analyzed to establish general background quality.

In addition, a number of shallow wells were placed adjacent to the landfill

to determine the areal distribution of gases in the surrounding alluvium produced by the decomposing refuse. Periodic gas samples were obtained to determine the magnitude of changes in distribution and composition.

Spadra Experimental Facilities

The Spadra test facilities are located at Landfill No. 2 of the County Sanitation Districts of Los Angeles County which is near the City of Pomona on Valley Boulevard in Walnut, as shown in Figure 4. The site, covering 128 acres is in a canyon tributary to the narrow formed by San Jose Creek and San Jose Wash, which separates the Puente and Jose Hills. Moderately sloped hilly

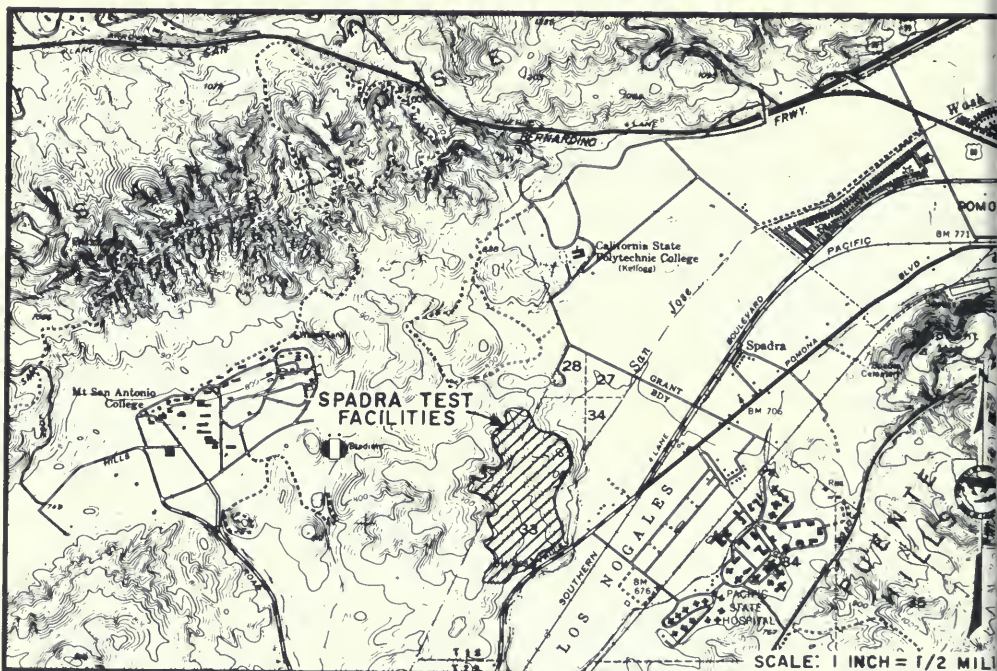


Figure 4—AREA MAP—SPADRA EXPERIMENTAL TEST SITE

of typifies the area. Elevations range from 660 to about 760 feet above sea level at the site. Drainage is to the southwest.

This site was used jointly by the University of Southern California to determine maximum placement density and subsequent shrinkage of refuse and by the Department to determine gas production and composition. The University of Southern California studies were conducted by Professor Robert C. Merz and Ralph Stone, under a research grant from the National Institute of Health.

Refuse test cells, each 50 feet square and 20 feet deep, were constructed at the Spadara site. Each cell has an observation well (4 1/4 inches in diameter) at the center of the fill, equipped with gas-sampling probes, one extending vertically into the side of the cell and the other projecting 2 feet into the bottom. Gases from the cells were analyzed periodically to determine the composition of the gas produced by the decomposing refuse.

Summary of Findings

Refuse was produced in California at a rate of about 4.5 pounds per capita per day, amounting to approximately 45,000 tons in 1966. Most of it was disposed of in sanitary landfills.

Refuse is composed of both organic and inorganic compounds. The organic compounds are decomposed or stabilized by aerobic and anaerobic organisms to produce substances that will decompose no further. These products of decomposition include gases and soluble organic and inorganic compounds. If sufficient oxygen is available, these decomposition products may be dissolved, forming an aqueous solution, referred to as leachate.

The quantity of leachate depends on the water balance for each particular site, which is equal to the applied water minus runoff, evapotranspiration losses, and moisture retention by the soil-

refuse complex (about 1 inch per foot). Predominant materials leached from refuse are organic matter, chloride, sulfate, potassium, calcium, and sodium.

4. Gas production varies over a wide range, with a maximum carbon dioxide concentration of about 90 percent by volume and a maximum methane concentration of about 55 percent by volume as determined by experiments. Production quantities vary directly with temperature, moisture content, garbage content, and aeration. Dry refuse and saturated refuse produce 0.035 and 0.210 cubic feet per pound of dry refuse, respectively, as determined experimentally. Gas movement rates are estimated to be 0.22 to 0.8 feet per day vertically and 0.24 to 1.4 feet per day horizontally in undisturbed alluvial soils.

5. Ground water is often impaired by refuse decomposition products whenever water is allowed to pass through the decomposed material in such quantities as to eventually reach the ground waters of the area.

6. Leachate impairment of ground water causes temporary increases in organic material and permanent increases in mineral constituents. Impairment is typified by several-fold increases in total dissolved solids, total hardness, chloride, and sulfate. Such increases may last several years.

7. Carbon dioxide effects on ground water are increases in hardness and bicarbonate. Depending on the pH after carbon dioxide absorption, water may become corrosive.

8. Pollution does not necessarily occur at the same time a landfill is constructed. Completed fills can set for years before any effects on ground water are detected.

9. Landfill sites can be classified on the basis of their physical characteristics and the various types of refuse. By modifying a site--usually by the construction of a physical barrier--the

ground water can be protected. This protection may be great enough to upgrade a site to a higher classification.

10. The main economic factors determining the feasibility of using a site for a landfill are land, haul distance, cost of construction and operation, cost of providing protective works, and value of land created by the landfill.

Conclusions

1. Products of refuse decomposition will threaten to impair ground water quality to various degrees wherever refuse is deposited on land.

2. Landfill site selection, types of refuse deposited, construction and operation techniques, and use of the completed fill may have considerable

impact on the quality of the underlying ground waters.

3. As the use of the ground waters of California increases with time, regulations on landfill disposal of refuse will trend toward requirements for complete protection, with increased use of physical barriers.

4. To be usable, a classification system for landfill sites should be based on the degree of protection afforded ground water by the geologic, hydrologic, and topographic characteristics of the sites.

5. From an economic standpoint, the degree of protection provided for receiving ground water should be governed by the decrease in economic value of the waters as compared with the cost of providing the protective works.

CHAPTER II. GEOLOGY AND HYDROLOGY

geologic and hydrologic characteristics of sites were important factors in the selection of landfills for this study, especially at the Azusa, Mayflower, and Toll Canyon landfill areas. A description of the geology and hydrology of the Spadra test site is not included because the study relates only to a discussion of several test cells which are geologically unrelated to the areal ground waters.

Azusa and Mayflower Landfill Sites

The Azusa and Mayflower landfill sites occupy the central portion of San Gabriel Valley and have similar geologic and hydrologic features as described in Appendix A of the Department's Bulletin No. 104-2. (5) For this reason, they are discussed together in the following sections.

Geology

Both the Azusa and Mayflower landfill sites are underlain by a thick sequence of alluvial fill that constitutes the freshwater-bearing sediments of the basin in San Gabriel Ground Water Basin. This is Recent and Pleistocene alluvial detritus, which is generally structurally undeformed, extends throughout the broad expanse of the San Gabriel Valley. Its thickness ranges from a few feet near the valley margin to depths of several thousand feet in the interior portion of the basin. The source of this Quaternary continental detritus is primarily the basement complex of the San Gabriel Mountains, which are north of the study area.

A relatively thin layer of Recent alluvium (Qal) mantles the underlying older alluvium (Qoal), as shown in Figure 5.

These materials are unweathered, unconsolidated, mainly coarse grained with only small amounts of silts and clays. They form coalescing alluvial fans in areas of moderate relief, and they fill the stream channels in the topographically low relief areas.

Older alluvial detritus underlies a major portion of the valley floor and generally outcrops along the flanks of the San Gabriel Valley. These sediments are highly weathered, unconsolidated, and essentially coarse grained, complemented by a lesser amount of fine grained constituents. Surficially, these sediments form dissected alluvial fans and generally occur as low-lying hills surrounded by Recent deposits.

The coarse and unconsolidated nature of these sediments indicates high permeabilities, especially near the center of the basin, where the sanitary landfill sites are located. Their physical character, coupled with the absence of significant structural barriers to flow, suggests the existence of very favorable conditions for percolation and infiltration of naturally and artificially applied waters. Characteristics of the alluvial fill forming the water-bearing zone in the vicinity of the landfill sites are presented in Table 1.

Hydrology

The discussion of the hydrology of the Azusa and Mayflower landfill areas is based on results of a study by the Department. (5) The base hydrologic period established by the study was the 27-year period from 1933-34 through 1960-61.

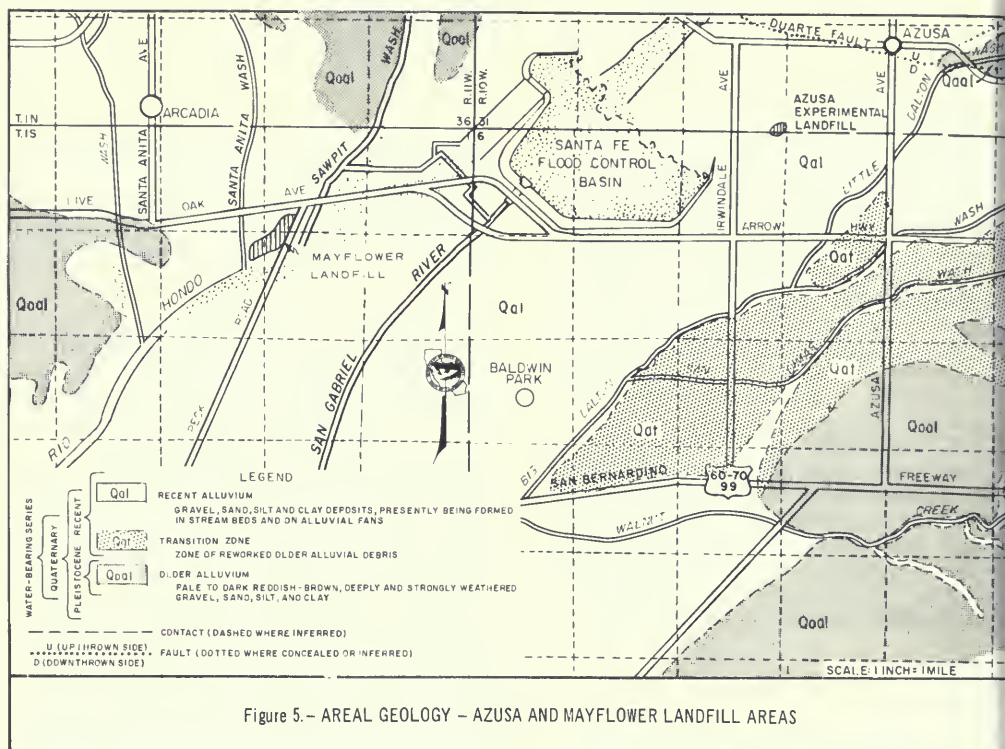


TABLE 1
CHARACTERISTICS OF THE SAN GABRIEL GROUND WATER BASIN IN
THE VICINITY OF THE AZUSA AND MAYFLOWER LANDFILL SITES (5)

Transmissivity	1.5 million gal./day/ft. width
Permeability	2,000 gal./day/ft. ²
Specific yield	9 - 14 percent
Safe yield (total basin, 1960 conditions)	100,000 acre-ft./yr.
Storage capacity	12,000 acre-ft./ft. depth
Total storage capacity	9.5 million acre-feet
Percolation rate	2 inches/hr.

o, 90-year normal seasonal precipitation contours (1872-1962), published by the Los Angeles County Flood Control District's "Biennial Report on Hydrologic Data", July 1, 1964, were used to depict areal variation of rainfall to indicate continuity between these sites and the Scholl Canyon site.

Water Supply. The average water supply for the 27-year base period was 343,300 acre-feet per year. Average yearly contributions to the supply were: direct precipitation, 47 percent; surface inflow, 29 percent; subsurface inflow, 6 percent; and freshwater import, 18 percent.

Average seasonal precipitation in the San Gabriel Valley varied with location and elevation, ranging from about 16 inches at Whittier Narrows to 22 inches

at the base of the mountains. Figure 6, an isohyetal map for the 90-year period from 1872 to 1962, depicts the areal variation in precipitation for the study area. Lines of equal average seasonal precipitation for the 5-year period from July 1960 through June 1965 are also shown in Figure 6. A summary of yearly precipitation and average for each station used in the determination of the 5-year mean is given in Table 2. Average precipitation for this 5-year period, which is about 6 inches lower than the 90-year mean, indicates the drought conditions prevalent in Southern California throughout this study period.

Water Use. The San Gabriel Ground Water Basin is a large and important reservoir, not only as a source of ground water, but also as a storage and distribution facility. Numerous wells

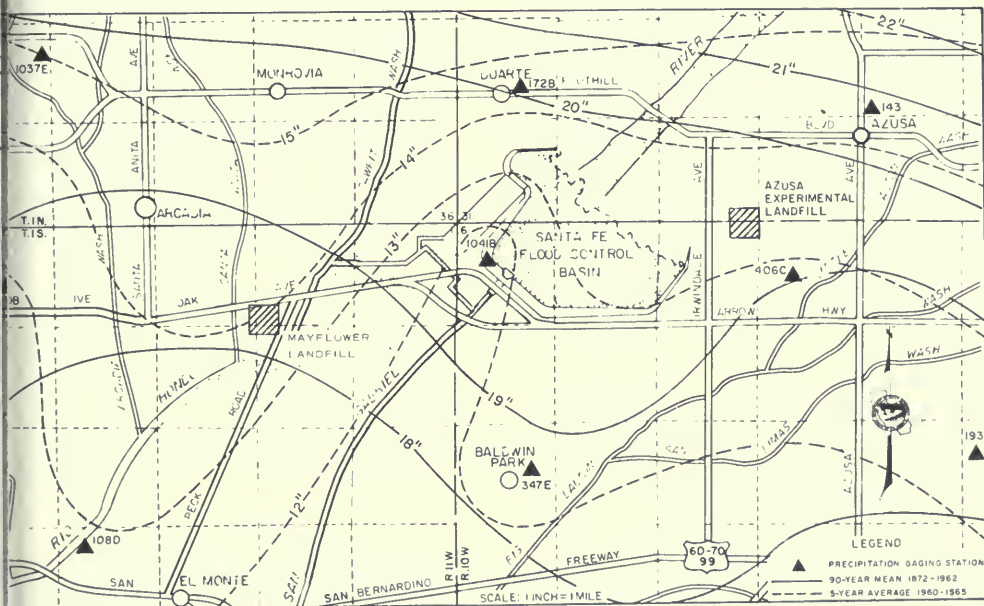


Figure 6 - AREAL PRECIPITATION - AZUSA AND MAYFLOWER LANDFILL AREAS

TABLE 2
PRECIPITATION DATA — 5-YEAR AND 90-YEAR AVERAGES,
AZUSA AND MAYFLOWER LANDFILL AREAS
In inches

Station	Year (July-June)					5-year average	90-year me. 1872-1962
	1960-61	1961-62	1962-63	1963-64	1964-65		
Arcadia Arboretum Z6-0251-01* L.A.C.F.C.D. #1037E	6.92	25.92	11.09	15.16	15.89	15.00	19.92
Azusa City Park Z7-0410 L.A.C.F.C.D. #143	7.70	23.22	10.18	13.98	15.81	14.18	20.55
Baldwin Park Experimental Station Z7-0455 L.A.C.F.C.D. #347E	5.42	21.92	8.96	11.63	14.38	12.46	19.56
Covina Temple Z7-2090 L.A.C.F.C.D. #193	5.78	19.47	9.79	12.61	14.55	12.44	18.21
Duarte-Blain Z7-2523-01 L.A.C.F.C.D. #172B	6.26	25.43	11.02	14.62	15.47	14.56	20.06
El Monte Fire Station Z7-2779-01 L.A.C.F.C.D. #108D	5.67	24.34	9.42	10.94	14.01	12.88	17.17
Santa Fe Dam Z7-7926 L.A.C.F.C.D. #1041B	5.18	19.35	8.83	12.19	12.75	11.66	19.50
Temple City Fire Department Z6-8848-01 L.A.C.F.C.D. #480B	5.46	22.71	8.92	12.31	13.72	12.62	18.00
West Azusa Irrigation Company Z6-9531-71 L.A.C.F.C.D. #406C	6.12	21.46	9.70	12.54	14.39	12.84	19.02

* Department of Water Resources numbering system presented in the Office Report, "Index of Climatological Stations in California, 1966". April 1966.

penetrate its alluvial deposits and extract water for domestic, industrial, and irrigation uses. In 1960, an estimated 430 wells produced 193,000 acre-feet of water from the basin. In the same year, approximately 14,000 acres of valley land were under irrigation, and 56,000 acres were urbanized.

Elements of the water utilization and disposal picture include consumptive use, surface and subsurface outflow, freshwater export, and waste-water export. The average seasonal water utilization for the 27-year base hydrologic period was 350,800 acre-feet, 50 percent of which was consumptively used.

For 18 years, Southern California has had a drought, with an accumulated precipitation deficiency of 50 inches. This, coupled with rapid urban expansion, resulted in a water supply efficiency of approximately 203,000 acre-feet for the 27-year base period. This deficiency was met by pumpage of ground water in storage, with a resulting decrease in storage and declining water levels throughout the basin. This is evidenced by water level measurements in the test wells at the Azusa Experimental Landfill site, and it is shown in Figure 7. In addition, real ground water level contours for historic high water conditions in 1944 and 1964 are depicted in Figure 8.

In general, areal water levels in the vicinity of the landfill sites have declined approximately 90 feet since 1944. During the study, water levels in the Azusa test wells dropped 30 feet from December 1962 through June 1965, and 125 feet from historic high levels (Figure 9).

Scholl Canyon Landfill Site

Scholl Canyon is an east-west trending, moderately steep V-shaped valley that lies in the southwest portion of the San Rafael Hills within the City of Glendale. This canyon is approximately 1/2 miles long and 1/4 mile wide. It

is drained by a westerly flowing intermittent stream that is tributary to the San Fernando Ground Water Basin.

Geology

The entire sanitary landfill area is underlain and flanked by a pre-Cretaceous basement complex (pKbc) of faulted and fractured igneous and metamorphic rocks, as reported by Taweel⁽²⁵⁾ and shown in Figure 10. Outcrops consist chiefly of highly weathered granites, gneisses, and schists. This bedrock is essentially impermeable and nonwater bearing, even though small amounts may be found within joints and fractures.

Along the valley floor, Recent alluvium (Qal) overlies the basement complex from the landfill toe, which is a short distance upstream from a debris dam, west to the mouth of the canyon and into the San Fernando Valley. These deposits consist mainly of unweathered sands and gravels with interbedded silt and clay lenses. The coarse materials are water bearing and will yield water in appreciable amounts, while the finer sediments are less permeable and do not transmit water quite as readily. Because these permeable deposits exist as a thin layer in the vicinity of the debris dam, underflow from the landfill area is greatly restricted at that locale. It is possible that additional underflow occurs through the joints and fractures of the basement complex.

Exposures of Pleistocene older alluvium (Qoal) are found in the southern portion of the study area, from the vicinity of the mouth of Scholl Canyon southeast and then east, roughly paralleling Hill Drive, where the older alluvium is in contact with basement complex rocks. Recent detritus blankets the older alluvial materials west of an alignment projected south-southwest from the area near the lower extremity of the canyon. These older alluvial sediments are characterized by highly weathered semiconsolidated to unconsolidated,

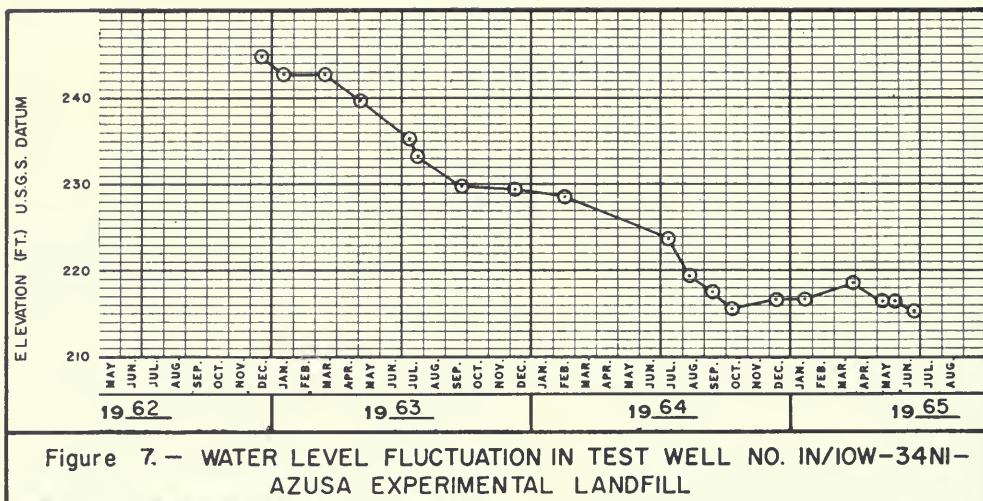


Figure 7. — WATER LEVEL FLUCTUATION IN TEST WELL NO. IN/IOW-34NI—AZUSA EXPERIMENTAL LANDFILL

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

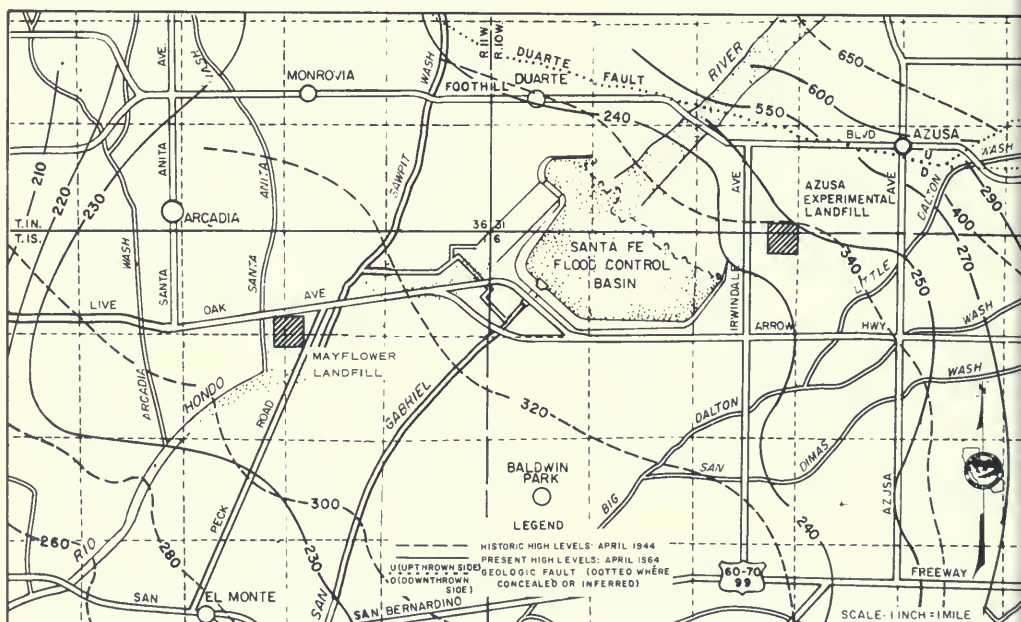


Figure 8. — LINES OF EQUAL GROUND WATER ELEVATION — AZUSA AND MAYFLOWER LANDFILL AREAS

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

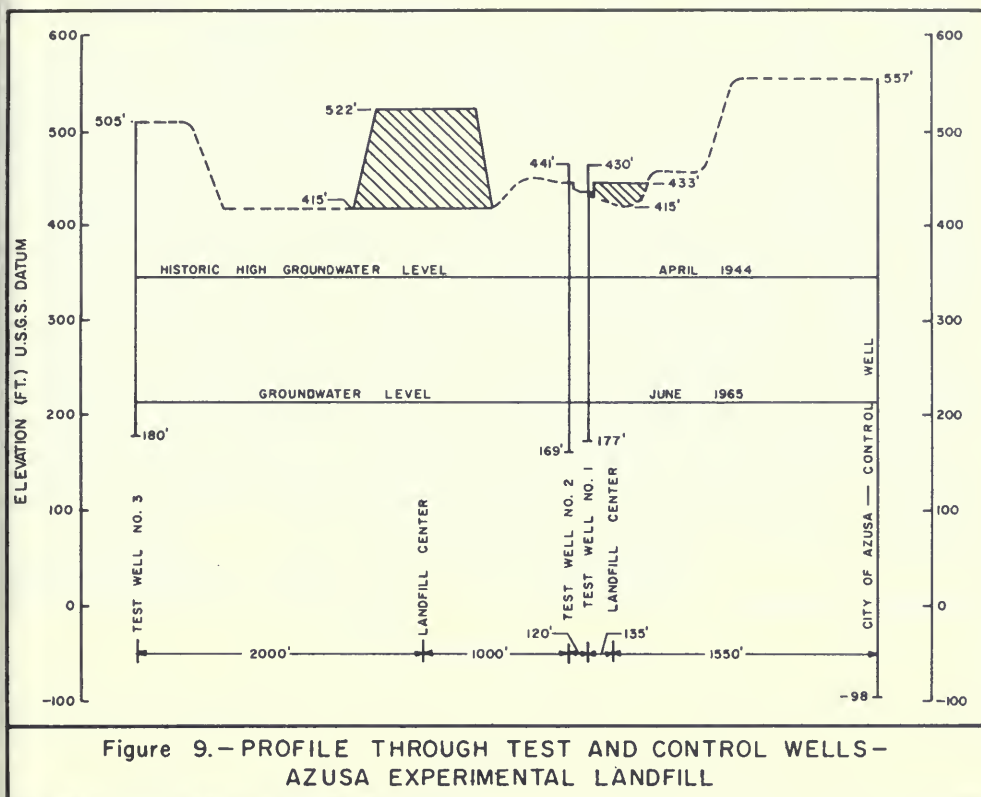


Figure 9.—PROFILE THROUGH TEST AND CONTROL WELLS—
AZUSA EXPERIMENTAL LANDFILL

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

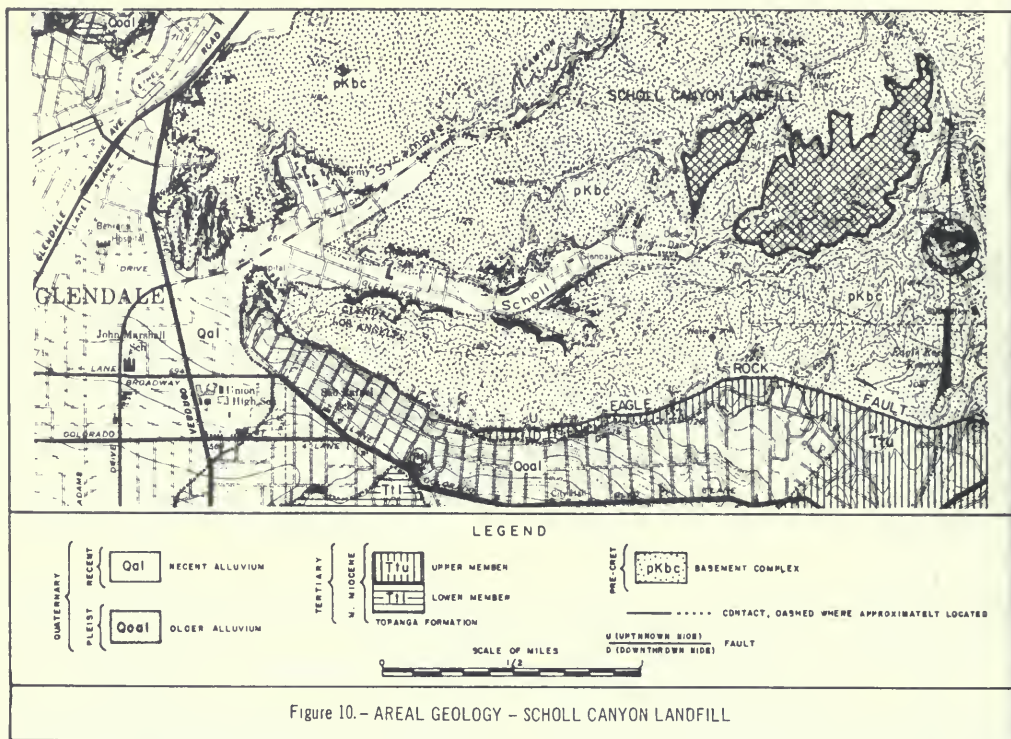
water-bearing, reddish-brown gravels, sands, silts, and clays. The coarser sediments yield considerable amounts of water.

The middle Miocene upper member of the Topanga Formation (Ttu) is found only in the southeast portion of the study area. These sediments are in fault contact (Eagle Rock fault) with the basement complex to the north, and they are covered by older alluvial materials to the south. The lower member of the Topanga Formation (Ttl) is found only along the mid-southern border of the study area. This unit is flanked by older alluvial sediments to the north.

Hydrology

Scholl Canyon is tributary to the San Fernando Valley, which is underlain by the San Fernando Ground Water Basin. The surface and ground waters of this basin are used extensively for domestic, agricultural, and industrial purposes, and have been and will continue to be important sources of water supply for the Los Angeles metropolitan area.

As indicated by the preceding geologic discussion, there could be underflow from the site to the basin, even though it is restricted at the debris dam.



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Test facilities at the site were used to determine the quality of leachate only. Therefore, the hydrologic discussion is limited to precipitation and applied water (by irrigation), factors that directly affect the production of leachate.

Precipitation. Water applied naturally to the landfill comes from direct precipitation and runoff from precipitation in the higher reaches of the watershed. Direct precipitation contributes the major portion of this water, since lined drainage swales carry runoff downstream of the fill and prevent percolation.

The average seasonal precipitation in upper Scholl Canyon ranged from 18 to 20 inches, increasing from lower to higher elevations, as shown in Figure 11.

Average seasonal precipitation for the 5-year period from July 1960 through June 1965 was about 13 inches. A summary of yearly and average seasonal precipitation for stations used in the determination of the 5-year mean is presented in Table 3.

Irrigation. Water is artificially applied to the site for irrigation of baseball diamonds on top of first-completed portion of the fill, vegetative growth for face slope stability, and the park area at the foot of the fill. Bimonthly figures for irrigation water for the period from October 1962, when the fill was completed, to July 1966 are presented in Table 4. Irrigation water amounted to about 29.5 million gallons, or an average of 820,000 gallons per month, during this study.

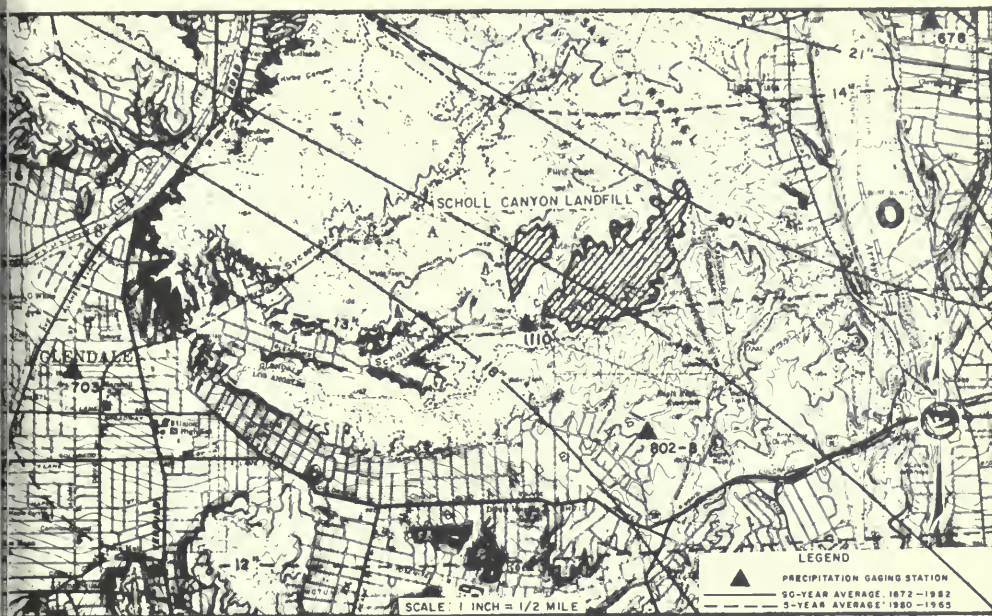


Figure 11.- AREAL PRECIPITATION - SCHOLL CANYON LANDFILL

TABLE 3
PRECIPITATION DATA - 5-YEAR AND 90-YEAR AVERAGES,
SCHOLL CANYON LANDFILL AREA
In inches

Station	Year (July - June)					5-year average	90-year average
	1960-61	1961-62	1962-63	1963-64	1964-65		
Apple Rock Reservoir Z6-2605-02* L.A.C.F.C.D. #802-B	7.32	21.28	9.89	10.32	14.19	12.60	17.61
Glendale-Jones No. 1 Z6-3450-01 L.A.C.F.C.D. #216	6.55	21.46	9.29	11.44	13.38	12.42	17.45
Glendale-McIntyre Z6-3450-02 L.A.C.F.C.D. #703	6.40	21.93	9.49	10.70	13.36	12.38	17.61
Scholl Debris Basin Z6-8038-51 L.A.C.F.C.D. #1110	7.14	21.23	9.67	13.02	14.99	13.21	18.20
Idon Reservoir-Pasadena Z7-6719-18 L.A.C.F.C.D. #678	7.59	23.39	11.46	13.03	16.41	14.38	21.10

Department of Water Resources numbering system presented in the Office Report, "Index of Climatological Stations in California, 1965", April 1966.

TABLE 4
IRRIGATION WATER,
SCHOLL CANYON LANDFILL - STAGE I
In gallons

Period covered	Applied water*	Accumulated total
August-September 1962	5,250	5,250
October-November 1962	543,050	548,300
December 1962-January 1963	555,000	1,103,300
February-March 1963	2,272,500	3,375,800
April-May 1963	1,288,500	4,664,300
June-July 1963	2,856,000	7,520,300
August-September 1963	2,758,500	10,278,800
October-November 1963	930,750	11,209,550
December 1963-January 1964	1,180,500	12,390,050
February-March 1964	967,500	13,357,550
April-May 1964	1,422,000	14,779,550
June-July 1964	2,136,000	16,915,550
August-September 1964	2,031,750	18,947,300
October-November 1964	1,221,000	20,168,300
December 1964-January 1965	915,750	21,084,050
February-March 1965	1,194,000	22,278,050
April-May 1965	2,591,250	24,869,300
June-July 1965	4,556,250	29,425,550

Note: The landfill was completed October 15, 1962, and cover vegetation was planted December 27, 1962. Water applied prior to December 27, 1962, was used for sideslope, stabilization, construction, and irrigation of park.

* Applied water quantities obtained from City of Glendale, Department of Parks and Recreation.

CHAPTER III. DECOMPOSITION OF REFUSE

use contains materials that are organic and inorganic compounds. Organic matter present in common use (paper, vegetation, garbage, etc.) undergoes natural decomposition through biological processes. Inorganic materials (rock, concrete, glass, etc.), which undergo no appreciable decomposition, are not included in this discussion.

The Decomposition Process

Decomposition stabilizes organic matter, i.e., it breaks down the organic matter to simple substances that will decompose no further. This process is carried out by bacteria and other microorganisms that use up the organic matter and certain complex mineral constituents as nutrients. Biochemical reactions, collectively known as respiration, provide chemical energy for synthesis. Organic matter can be stabilized by aerobic or anaerobic organisms.

Aerobic Decomposition

Aerobic decomposition will occur when sufficient amounts of molecular (free) oxygen are available for use by bacteria. The source of oxygen may be the atmosphere or water containing a comparatively small amount of dissolved oxygen. Aerobic biochemical reactions consist of the progressive oxidation of organic matter by biota to produce carbon dioxide and water, and the oxidation of nitrogen and sulfur to nitrates and sulfates:

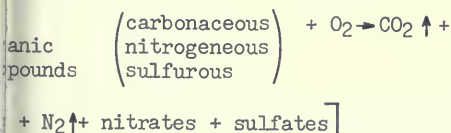
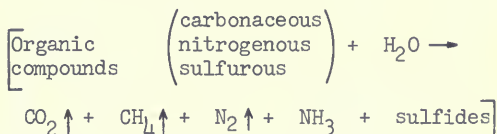


Figure 12 depicts the cycles of carbon, nitrogen, and sulfur in aerobic decomposition. Nitrogenous compounds are oxidized first to ammonia, then to nitrites, and then to nitrates. Production of nitrogen gas may occur by a reduction process. Sulfurous compounds are oxidized through a similar cycle to sulfates. Carbonaceous matter is completely broken down to carbon dioxide and water. This figure also shows the dependence of each phase of the cycle on the air and water reservoir. Free nitrogen, which is not usable by higher plants, is produced in the decomposition phases. Free nitrogen is oxidized to nitrates, a form that can be used in the life processes.

Anaerobic Decomposition

When the air and water reservoir becomes exhausted or devoid of molecular oxygen, the respiration demands of aerobic organisms can no longer be satisfied and the aerobic bacteria cease to function. Their place is then taken by anaerobic or facultatively anaerobic bacteria that grow and liberate energy by drawing upon the oxygen of the organic material itself.

The cycles of nitrogen, carbon, and sulfur in anaerobic decomposition are depicted in Figure 13. Anaerobic decomposition generally occurs according to the following equation:



Initial products of decomposition include organic acids, acid carbonates,

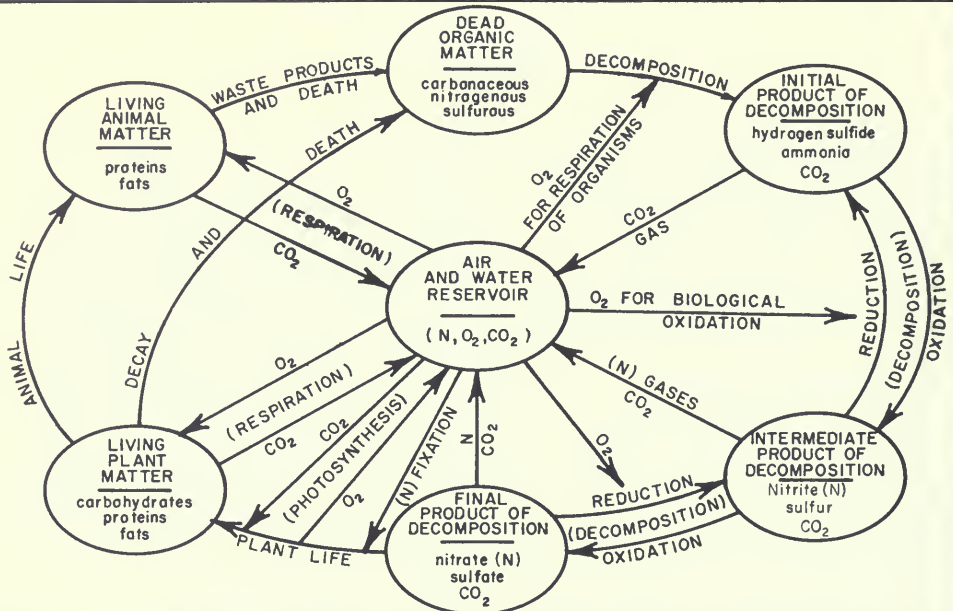


Figure 12.-AEROBIC DECOMPOSITION - NITROGEN, CARBON, & SULFUR CYCLES

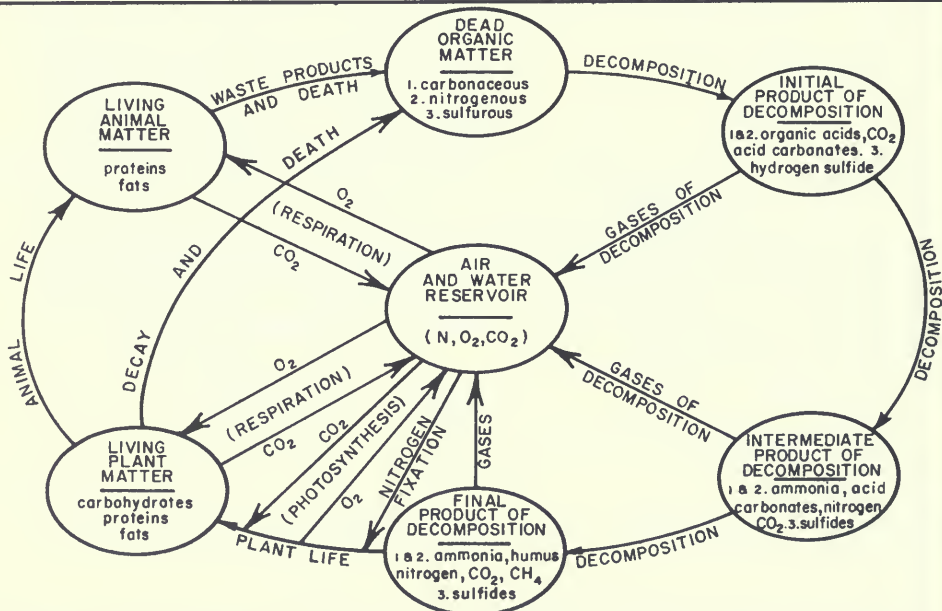


Figure 13.-ANAEROBIC DECOMPOSITION - NITROGEN, CARBON, & SULFUR CYCLES

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

Adapted from Gordon M. Fair and John C. Geyer, "Water Supply and Waste Water Disposal." (21)

carbon dioxide, and hydrogen sulfide. Organic compounds undergo successive decomposition to ammonia, nitrate, humus, carbon dioxide, methane, and sulfides.

The cycle continues as various end products are assimilated by plants, which are used by animals in the construction of the organic waste matter that maintains the cycle.

Each organic compound is stabilized at a rate that depends on its relative energy level; that is, energy available to support bacterial respiration.

At any one point in time, various organic materials are undergoing stabilization at various points in their respective decomposition cycles. Therefore, a composite of many decomposition products is produced that is characteristic of that particular point in time. In other words, it is in a dynamic state, continually changing.

Leachate

Leachate is a water solution consisting of dissolved minerals and gases derived from refuse decomposition through respiration reactions and from soluble material in the refuse. The formation and movement of leachate are discussed below.

Formation

Leachate formation is entirely dependent upon the presence of excess water. Water not only has a pronounced effect on decomposition by providing a reservoir for oxygen and other gases to

support the decomposition cycle, but also provides transportation for waste products. The water balance, or budget, for a particular landfill will significantly affect the rate of refuse decomposition, the production and character of decomposition products, the movement of leachate, and subsequent impairment of ground water. The water budget is defined by the following equations:

$$W_a = R + I + E \quad (1)$$

where:

$$I = M_{rs} + M_{rr} + L \quad (2)$$

then:

$$W_a = R + E + M_{rs} + M_{rr} + L \quad (3)$$

where: W_a = applied water

R = runoff

I = infiltration

E = evapotranspiration

M_{rs} = change in moisture retention by soil

M_{rr} = change in moisture retention by refuse

L = leachate

The following sections are devoted to the quantitative determination of the above elements of the water budget, excluding leachate, which will be discussed in detail in later chapters of this report.

Water Application. Water can be applied naturally by precipitation or artificially by irrigation. Runoff from adjacent areas is assumed to be excluded from the refuse by drainage facilities along the perimeter of the fill. It is also assumed, for purposes of this discussion, that the fill will not be inundated by rising ground water.

The amount of water applied to a landfill is a very important parameter in the design of a landfill cover system. Through the use of equation (3) above, limiting quantities of applied water can be determined for allowable quantities of leachate. In a situation where leachate could be disposed of

safely, an analysis of historical rainfall records or, in the case of irrigation, anticipated water application rates, would be used to size leachate disposal facilities.

Runoff. Transposing terms in equation (1) above, gives an equation for the determination of runoff as follows:⁽²²⁾

$$R = W_a - (I + E) \quad (4)$$

The relationship between runoff and infiltration is used to determine the amount of applied water that infiltrates the landfill cover. The following discussion is devoted to the determination of infiltration characteristics and rates for various plant-soil cover systems. From this, the amount of infiltration can be calculated and inserted in equation (4) to obtain runoff.

The rate and amount of infiltration is dependent on the type of soil, vegetative cover, moisture content of the soil, slope, and quantity of applied water. The type of soil (grain size and decomposition) has a pronounced effect on infiltration by virtue of its characteristic permeability - highly permeable sands and gravels having the highest rates of infiltration. Infiltration rates for certain soil groups are presented in Table 5.

TABLE 5

INFILTRATION RATES FOR BARE SOILS⁽²⁷⁾
IN INCHES/HOUR

Soil type	:One-hour infiltration rate range
Gravel; sand gravel	1.0 - 4.0
Sand; friable silt loam	0.5 - 1.0
Loam	0.1 - 0.5
Clays	0.01 - 0.1

Vegetative cover is important in several respects. First, the growth of roots creates large pores resulting in increased soil permeability. Second, foliage protects the surface against compaction and erosion by raindrops and encourages the formation of a surface layer of humus, which has a high permeability. Third, it retards surface flow velocity, thereby increasing⁽²³⁾ retention time, which promotes infiltration. Cover factors, or the ratios of infiltration for a soil with a particular cover to the same soil with no cover, are included in the following one-hour infiltration rate ranges:

Grass (park or golf course) 3.0 to 7.5 inches/hour
 Grass (30 to 80 percent density, i.e., pasture) 2.0 to 3.0 inches/hour
 Grass (less than 30 percent density, i.e., native grass, weeds, and brush) 1.0 to 2.0 inches/hour

Soil moisture conditions preceding a rainstorm or period of irrigation limit infiltration by reducing available soil pore space or reservoir capacity. When the soil is initially dry, capillary forces move infiltrating water downward and outward at a maximum rate. However, as moisture content increases, capillary forces decrease until, at saturation, they are zero. Under conditions of previous wetting, soil saturation is reached more rapidly, thus reducing infiltration and increasing runoff.

The relationship between rainfall intensity and infiltration is depicted in Figure 14. The curves of Figure 14 represent varying conditions dependent on soil type, cover, and preceding moisture conditions. Use of these curves is illustrated by Table 6.

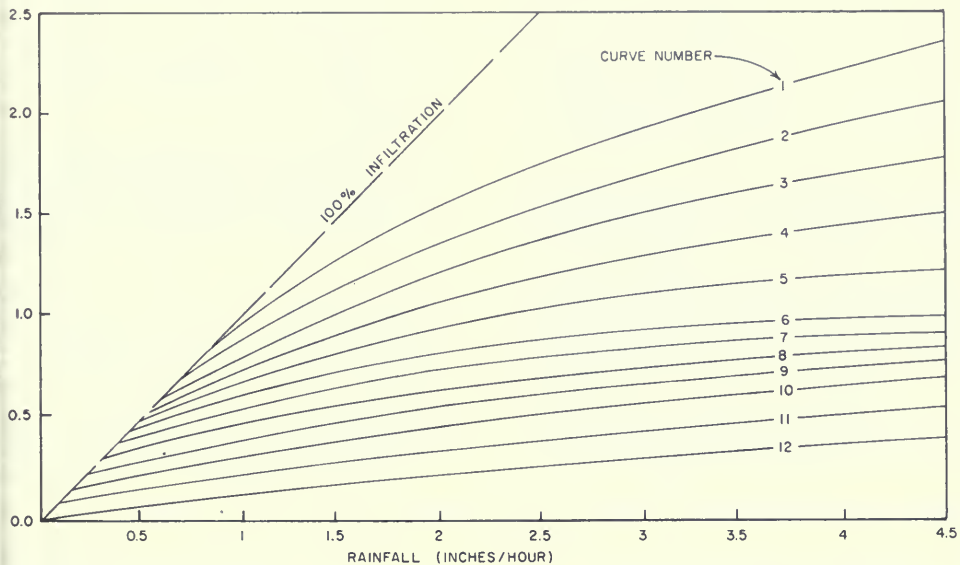


Figure 14 - INFILTRATION WITH RESPECT TO RAINFALL INTENSITY

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

From U.S. Bureau of Reclamation, "Design of Small Dams".

TABLE 6

REPRESENTATIVE VARIATION OF RAINFALL - INFILTRATION CURVES WITH SOIL TYPE, COVER, AND PRECEDING MOISTURE CONDITIONS⁽²⁷⁾

		M values*				
Soil type	Cover	0.2	0.4	0.6	0.8	1.0
		Curve number				
Sandy loam	Turf	1	2	4	6	8
Sandy loam	Bare	3	4	6	8	10
Cayey loam	Turf	2	3	5	7	9
Cayey loam	Bare	5	6	8	10	12

* increases with degree of soil saturation.

$$M = \frac{e(d_{60} + 1)}{10} \text{ for non-irrigated areas}$$

$$M = \frac{e(d_{60} + 1)}{10} + A \text{ for irrigated areas}$$

such as parks, where A is allowance for irrigation = 0.11

$$\text{where: } e = \text{evaporation} = \left(0.9 - \frac{e_{60}}{e_{\text{annual}}}\right)$$

where: (e_{60}) = pan evaporation for preceding 60 days

(e_{annual}) = mean annual pan evaporation

d_{60} = weighted preceding 60-day precipitation as:

$$d_{60} = p(1-4) + p(\frac{5-9}{2}) + p(\frac{10-14}{4}) + p(\frac{15-30}{6.67}) + p(\frac{31-60}{10})$$

The slope of the landfill cover has a pronounced influence on infiltration, which varies inversely with the degree of slope. To reduce infiltration to a minimum, the degree of slope of the cover should be a maximum, commensurate with slope requirements of the particular use to be made of the finished site and the necessity of maintaining slope stability.

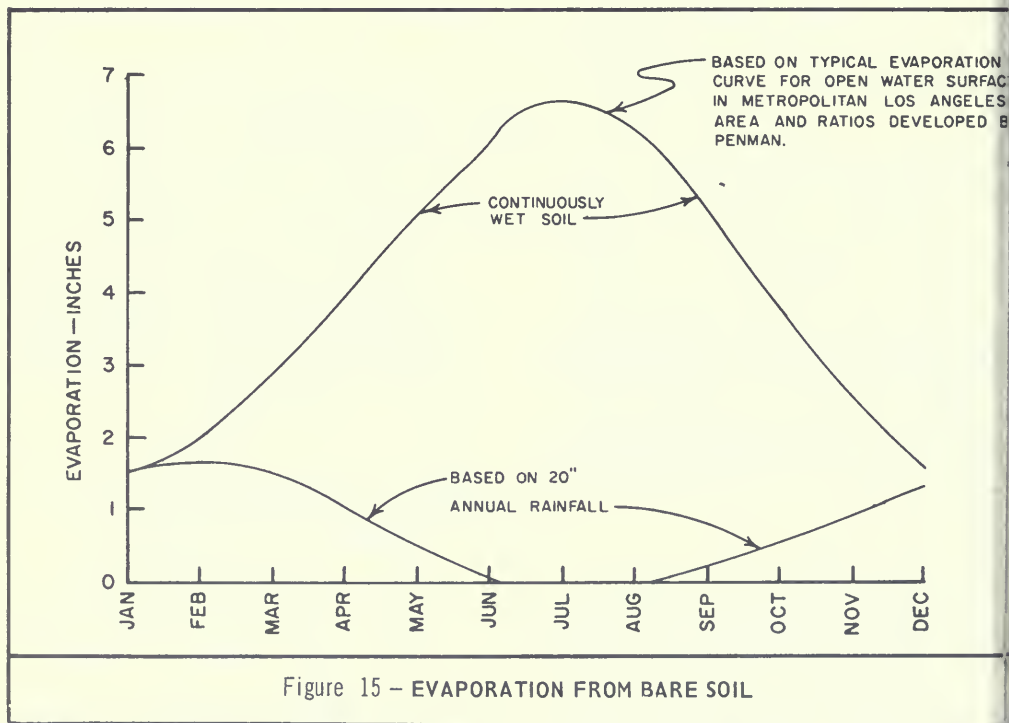
Evapotranspiration. Evapotranspiration, synonymous with consumptive use in this discussion, is defined as the total quantity of water lost to the atmosphere from the soil-plant system. Evapotranspiration is controlled by climatic factors, such as temperature, wind, and humidity, and by soil moisture conditions.

With respect to soil moisture, two conditions arise. The first condi-

tion is that of continuous soil wetting (maintenance of soil moisture above wilting point) through irrigation. The second condition is that of intermittent wetting by precipitation (soil moisture above wilting point only during periods of excess rainfall).

Evapotranspiration varies with the type of soil-plant system that forms a landfill cover. Types of cover commonly found are bare soil, native brush and weeds, and grass or turf.

Evaporation curves for bare clay loam soils are shown in Figure 15. For a continuously wet soil, evaporation amounts to approximately 90 percent of equivalent open water surface loss. For nonirrigated soil, evaporation approximates half the annual average precipitation. To allow for reduced



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evaporation from more permeable soils, ratios of 0.6 and 0.8 for fine sand and sandy loam, respectively, should be applied to the values in Figure 15.

Evapotranspiration losses from a grass turf cover are slightly lower than bare soils. From a study by H. L. Penman, entitled, "Natural Evaporation from Open Water, Bare Soil and Grass", the following ratios of evaporation from turf to evaporation from open water with respect to time of year were obtained:

- Feb. = 0.6
- Apr. = 0.7
- Aug. = 0.8
- Oct. = 0.7

Through the application of these ratios to a curve of open water surface evaporation versus time, an evapotranspiration

curve, or consumptive use, for irrigated grass can be developed for any area. For example, the consumptive use curve shown in Figure 16 for irrigated grass is based on the above ratios and a typical evaporation curve for an open water surface in the Los Angeles metropolitan area. From this curve, the total consumptive use of water was 38.7 inches per year, which is compatible with values obtained in various water use studies in the Los Angeles area.

Consumptive use of water by native brush and weeds was assumed to be at the same rate as by irrigated grass during periods when precipitation maintained soil moisture above the wilting point. Monthly variation in consumptive use for nonirrigated brush and weeds, based on 20-inch rainfall, is shown in Figure 16.

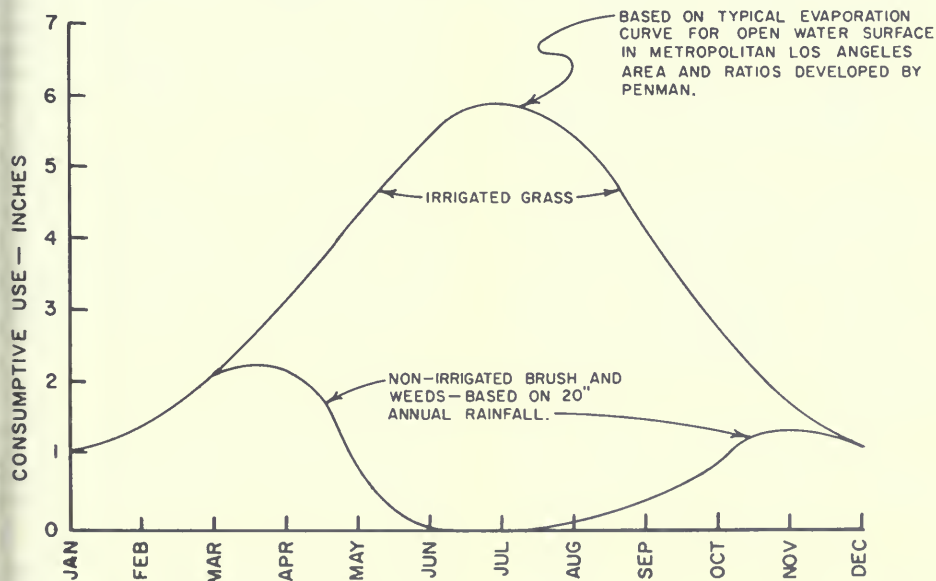


Figure 16 - CONSUMPTIVE USE OF WATER⁽⁹⁾

In addition to consumptive use, enough water must be applied to remove salts left by evaporation of irrigation water. A minimum water requirement represents a long-term average value for the deep percolation which must be permitted to remove salts and keep the surface soil fertile. Water requirement to remove salts is determined by:

$$l = \frac{(E-P) C_i}{C_o - C_i}$$

where l, E, and P are volumes of water required to remove salts, evapotranspiration, and precipitation, respectively; C_i is salt concentration in the irrigation water; and C_o is permissible salt concentration in the soil moisture. The annual water requirement to remove salts for grass irrigated with Colorado River water, with evapotranspiration amounting to 36 inches, is about 2.6 inches.

In general, the greater the excess water applied to remove salts, the greater will be the production of leachate.

Moisture Retention by Soil. Moisture will be retained by soil at field capacity, defined as the moisture content of soil after drainage by gravity is complete. If plants are present, soil moisture will be used until the wilting point (moisture content at a tension equivalent to the osmotic pressure exerted by the plant roots below which water is not available for plant use) is reached. The following tabulation gives moisture contents for various soils at field capacity and the wilting point.

Soil type	Field capacity (in./ft.)	Wilting point (in./ft.)
Sand	0.9	0.4
Loam	3.1	1.6
Clay	5.2	2.9

Field moisture tests would be required to determine conditions at site.

Moisture Retention by Refuse. Moisture retention capacity of refuse has been studied by Merz (7) of the University of Southern California and by the British government.(3)

In the studies by Merz, the retention capacity was found to be 2.5 inches per foot before initial moisture release (leachate), and 0.75 inches/foot afterward. The British government studies resulted in an estimated retention of 1 inch/foot of refuse depth. It appears that evaporation was considered in the British test but not in the test by Merz.

Movement

Water transports the leached materials within the landfill and externally in the subjacent alluvium.

The vertical movement of water in a porous medium is governed by the action of gravity and capillarity. In saturated soil, movement is primarily through larger pores under the influence of gravity, whereas movement in unsaturated soil is dominated by capillary forces.

The rate of movement of leachate from the landfill bottom into and through underlying soil is governed by the soil infiltration capacity, which in turn is limited by soil percolation rate. Percolation limits infiltration to the rate at which water is removed from the surface soil by gravity.

Initially, capillary forces move infiltrating water downward and outward until the soil reaches field capacity. At that time, capillary forces are negligible and movement occurs as percolation under the influence of gravity. The percolation rate increases from zero at field capacity to a maximum at saturation, at which time infiltration and percolation rates are equal. Infiltration rates for various soils are presented in Table 5.

Gas

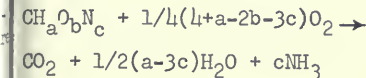
ses are produced during decomposition according to the equations presented earlier in this chapter. Movement of gases, unlike movement of moisture, is unrestricted by attraction to particles of the refuse or soil media. Gases, therefore, are free to circulate wherever they are impelled by influencing pressures. In the following discussion of gas production and movement, it is assumed that no water is applied to the fill.

Production

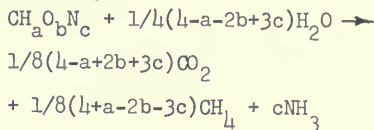
The composition of gases produced depends upon the composition of organic matter and the presence or absence of oxygen. The composition of organic matter (percentages of carbohydrates, proteins, and fats) will influence the composition and production of gas according to the particular compounds decomposing at any time. Carbohydrates such as sugars and starches in food wastes are rapidly digested. Proteins and fats, which occur mainly as garbage, are readily attacked by bacteria, and respiration products appear in the early life of the landfill. However, aerobic breakdown of fats can continue for years. Organic matter in combustible rubbish, which occurs mainly as the cellulose of paper and wood, decomposes very slowly. In a fill containing mostly combustible material, decomposition products found in early stages will be primarily those of carbohydrate reduction, in addition to products derived from proteins and fats.

Quantities of gas produced and composition of respiration products are computed on the basis of the following aerobic and anaerobic decomposition equations: (9)

aerobic:



Anaerobic:



Comparison of gas production by aerobic and anaerobic respiration shows that more carbon dioxide is produced under aerobic conditions as under anaerobic conditions. However, methane is also a major product of anaerobic decomposition.

Movement

Gas movement through refuse and adjacent soil occurs under the influence of gas pressure and density (concentration) gradients. Pressure differences or gradients arise in two ways. First, a net production or uptake of gas by the biota active in decomposing refuse will increase or decrease the pressure inside the fill. Second, the gas in the fill will produce a force on the cover or floor of the fill depending on the density of the gas formed and the density of the exterior atmosphere.

The movement of gases through porous media is governed by Darcy's Law when the flow is laminar. Because the soil is quite permeable to gases and the transfer area from fill to soil is relatively great, large pressure differences are unlikely, so gases can be considered incompressible fluids governed by the equation $V = \frac{K_g}{W_g} \text{ grad } P$ where K_g equals hydraulic conductivity, which depends on the medium through which the gas is flowing and the viscosity of the gas, W_g equals the unit weight of the gas, and $\text{grad } P$ equals the pressure gradient.

The movement of gases from a landfill was studied by Engineering-Science, Inc., at Azusa. (11) The study included determinations of quantities

and velocities of gas movement horizontally and vertically into the soil and the quantity of carbon dioxide passing through the fill cover to the atmosphere.

As previously mentioned, the quantity of CO_2 entering the soil with respect to time is a function of density and the gas concentration gradient between the fill and adjacent soil. At Azusa, an initial CO_2 bloom corresponded to the maximum rate of CO_2 contributed to the soil. With time, the concentration of CO_2 in the fill declined and the CO_2 in the soil increased, with a corresponding change in the CO_2 concentration gradient.

Early estimates were made of vertical and horizontal velocity in the adjacent soil under dry conditions, based on the time between CO_2 bloom in the fill and attainment of maximum concentrations in the test wells. Downward vertical velocity was estimated to be 0.8 ft./day, while horizontal velocity was estimated at 1.4 ft./day. Under a reduced gradient, gross horizontal and vertical velocities decreased to 0.24 and 0.22 ft./day, respectively.

In the absence of pressure gradients, rather than use Darcy's Law, Fick's Law of Molecular Diffusion was used to calculate net velocity, or transfer rate. The following equations were used:

$$(1) \ q = D_p \text{ grad } C \text{ (Fick's Law)}$$

$$(2) \ q_1 = C \frac{D_p}{L} \quad (\text{CO}_2 \text{ movement through cover to atmosphere})$$

$$(3) \ q_2 = C_0 \frac{D_p}{T} \quad (\text{CO}_2 \text{ movement into adjacent soil})$$

where:

q_1, q_2 = net velocity or transfer rate (ft./day) grad C = gas concentration gradient.

C = % CO_2 concentration in top layers of fill.

C_0 = % CO_2 concentration in fill at interface between bottom or side and soil.

D_p = CO_2 diffusivity (ft.²/day) in soil calculated from the equation: $D_p = D_0 (.66) P$, where D_0 is diffusivity of gas in space and P is porosity of soil. D_0 for CO_2 at various temperatures equals: 68°F, 15.0; 77°F, 15.4; and 86°F, 15.9. D_0 for methane at same temperatures equals 20.7, 21.3, and 21.9, respectively.

L = thickness of silt cover or distance between sampling points in adjacent soil (ft.).

T = time after diffusion commences (days).

To determine rates of gas movement Darcy's Law and/or Fick's Law may be used — depending on the presence or absence of pressure gradients in the medium.

CHAPTER IV. CHARACTER OF REFUSE DECOMPOSITION PRODUCTS

natural decomposition of refuse
leads to the formation of products
of the general form of gas, as discussed
in detail in the preceding chapter. If
sufficient water is available, these
products and soluble organics and
minerals may be dissolved, forming a
solution, referred to as leachate.

The character of decomposition products,
the quantity and composition of
leachate and gas, is influenced by a
number of factors. The most important
of these are: composition of the refuse,
mode of decomposition (aerobic or
anaerobic), and the presence of air and
water within the fill. Each of these
factors has been discussed in detail in
the preceding chapter. The inter-
relationship of these factors has been
worked out in several experiments and
examined in the following discussions.

Leachate

As previously stated, the formation
of leachate is entirely dependent on
the presence and movement of water with-
in and through refuse. The quantity
of leachate depends on the elements of
the water balance discussed in Chap-
ter III. Composition, or quality,
depends on the types and amounts of
material leached from the refuse.

Quantity of Leachate

Investigations have been made to de-
termine quantities of leachate ob-
tained from refuse subjected to var-
ious methods and amounts of water
application. The most applicable to

refuse disposal conditions in Califor-
nia are the studies by Professor Rob-
ert C. Merz⁽⁷⁾ of the University of
Southern California and by the British
Ministry of Housing and Local Govern-
ment.⁽³⁾

In a study at Riverside, California,
Merz used test bins to determine
leachate quantity and quality. The
two test bins were each 8 feet long, 4
feet wide, and 12 feet deep, with a
2-foot-radius half-round section of
culvert serving as the bottom and also
as a collection trough for the leachate.
The bins were packed with fresh,
domestic rubbish to a depth of 10 feet
and covered with 2 feet of soil.

The method of operation of the bins was
as follows: Bin number 1 received ar-
tificially applied water only. Bin
number 2 received water by natural pre-
cipitation only.

Volumes of applied water and resulting
leachate for bin number 1 are presented
in Table 7 as monthly values for the
study duration (January 1953 - July 1954).
Water was initially applied to bin num-
ber 1 at the rate of 20 gallons per day
(1 inch per day) until the refuse be-
came saturated. The rate was then re-
duced to weekly increments of 20 gallons.

Approximately 320 gallons were required
to saturate the refuse and produce an
appreciable amount of leachate. The
total amount of water applied during
the 19-month study was 1,820 gallons.
The total volume of leachate with-
drawn was 410 gallons, or 22.5 per-
cent of the applied water. Of the

TABLE 7
**APPLIED WATER AND VOLUME OF LEACHATE
 FOR A REFUSE TEST BIN (7)**
 In gallons

Year	Month	Applied water		Leachate produced	
		Per month	Cumulative	Per month	Cumulative
1953	January	160	160	0	0
	February	380	540	61	61
	March	100	640	61	122
	April	80	720	31	153
	May	80	800	43	196
	June	—	800	—	196
	July	40	840	32	228
	August	80	920	6	234
	September	80	1,000	26.5	260.5
	October	80	1,080	14	274.5
	November	100	1,180	0	274.5
	December	80	1,260	30	304.5
1954	January	80	1,340	7.5	312
	February	80	1,420	0	312
	March	100	1,520	38	350
	April	80	1,600	0	350
	May	80	1,680	18	368
	June	100	1,780	7	375
	July	40	1,820	8	383
Remainder of leachate withdrawn				≈27	≈410
Percent leachate				22.5	

aining applied water, approximate-
2,200 gallons were lost to the
osphere by evaporation and 210
ons were retained by the refuse.

number 2 received 18.7 inches of
fall, an inadequate amount to
duce leachate. This is due to
intermittent nature of the rain-
g, allowing a high rate of evap-
ation, and also to the moisture
ention capacity of the refuse.

lar investigations have been made
the British Ministry of Housing
Local Government. The quantity
quality of leachate were deter-
ed through the use of several
use test cells, each receiving
er in different amounts and under
ous methods of application. A
ond experiment was then made,
ng a much larger test cell and
osing the refuse to rainfall only.

the first set of experiments, six
ot lengths of drainpipe were as-
eet to form three cells, each
et long and 1 foot in diameter.
test cells were then packed with
sh refuse to a depth of 5-1/2 feet,
they were covered with several
nes of soil.

cells were operated as follows:
l 1 was saturated, and then 200
ililiters (mls) per day of distilled
er were applied (equivalent to an
ual rainfall of 30 inches); cell 2,
hout preliminary saturation, initially
eived 1,300 mls per day (197 inches
year), which were reduced to a
e equivalent to 83 inches per year
er three months, and after six
ths the cell was exposed to natural
nfall only; cell 3 was exposed to
ural rainfall only.

achate was obtained from the three
ls from the time saturation of ref-
was reached until the study ended.
time required to attain saturation
ied with the rate and frequency of
er application. Volumes of applied

water and resulting leachate for the
three test cells are presented in
Table 8.

The amount of water required to satu-
rate the refuse in cell 1 was 17.5 li-
ters, equivalent to 9.4 inches of rain.
The amount of leachate during February
was abnormally high because water that
had been frozen within the refuse was
released.

The refuse in cell 2 required more than
two weeks to attain saturation after
18.2 liters (9.8 inches) of water were
applied. After six months, when arti-
ficial application was discontinued and
the cell was exposed to rainfall only,
the rate of leachate formation corre-
sponded to that of cell 3, which was ex-
posed to rainfall throughout the study.

In cell 3, leachate appeared subsequent
to refuse saturation, which occurred
after six months of operation. After
saturation was attained, leachate
amounted to about 50 percent of applied
rainfall. The difference between the
amount of water applied and the leachate
obtained can be accounted for by evap-
oration loss and moisture retention by
the refuse.

The refuse test cell used in the second
experiment was 42 feet long, 35 feet
wide, and 6-3/4 feet deep. The cell
was filled with refuse to a compacted
depth of about 5 feet and covered with
18 inches of soil. Water applied was
by natural precipitation only.

Volumes of applied rainfall and result-
ing leachate are presented in Table 9.
The refuse became saturated during the
second month of operation. After satu-
ration, the amount of leachate formed
varied with the amount of rainfall.
Total rainfall for the study period
was 61,315 gallons (68.1 inches).
The total leachate was 25,228 gallons,
or 41 percent of applied water. After
the refuse became saturated, the for-
mation of leachate averaged about 46
percent of rainfall.

Quality of Leachate

Percolating water leaches or dissolves material of many types, in various stages of the decomposition cycle.

The quality of the leachate varies widely depending on the compound (fat, carbohydrate, or protein) being broken down, whether the decomposition is aerobic or anaerobic, and the amount of water present.

TABLE 8
VOLUME OF LEACHATE UNDER VARIED CONDITIONS
OF WATER APPLICATION (3)
In milliliters

Year	Month	Cell 1		Cell 2		Cell 3	
		Water added	Leachate produced	Water and rainfall added	Leachate produced	Rainfall added	Leachate produced
1953	August	1,960	67	12,740	0	3,364	0
	September	4,320	204	26,780	15,853	5,684	0
	October	5,400	1,871	17,188	13,019	6,873	0
	November	4,320	2,159	11,988	9,143	2,987	0
	December	3,920	2,704	10,878	5,755	871	0
1954	January	5,200	2,537	8,254	2,157	3,264	0
	February	4,320	6,708	5,845	9,677	5,845	1,765
	March	4,320	1,997	4,162	2,057	4,162	2,750
	April	3,800	1,854	1,914	0	1,914	320
	May	5,400	3,793	4,888	22	4,888	201
	June	3,960	2,659	8,410	5,460	8,410	5,840
	July	5,400	3,186	6,322	3,261	6,322	2,745
	August	<u>4,120</u>	<u>2,566</u>	<u>10,414</u>	<u>8,865</u>	<u>10,414</u>	<u>8,319</u>
TOTAL		56,440	32,305	129,783	75,269	64,998	21,940
Percent leachate			57	58		34	

TABLE 9
RAINFALL AND VOLUME OF LEACHATE
FOR A REFUSE TEST CELL⁽³⁾

Year	Month	Rainfall		Leachate
		Inches	Gallons	Gallons
1954	June	0.17	156	0
	July	2.22	2,035	14
	August	2.30	2,109	78
	September	1.25	1,146	8
	October	1.74	1,595	108
	November	4.26	3,905	1,775
	December	1.462	1,340	1,356
1955	January	2.124	1,947	1,485
	February	1.34	1,226	897
	March	0.79	725	380
	April	0.54	505	222
	May	4.00	3,667	916
	June	2.00	1,836	413
	July	0.51	463	150
	August	1.06	972	182
	September	1.385	1,270	143
	October	4.07	3,724	1,136
	November	2.25	2,063	1,162
	December	2.235	2,050	925
1956	January	4.155	3,810	2,784
	February	0.28	253	988
	March	0.92	843	384
	April	1.055	926	230
	May	0.325	298	106
	June	2.27	1,000	197
	July	3.415	3,130	483
	August	5.150	4,721	904
	September	2.625	2,407	1,065
	October	2.715	2,489	1,215
	November	0.49	449	139
	December	3.695	3,388	1,475+
1957	January	1.345	1,235	1,172
	February	<u>3.960</u>	<u>3,632</u>	<u>2,736</u>
TOTAL		68.106	61,315	25,228
Percent leachate				41

Several investigations have been made to determine leachate quality under various conditions of applying water to refuse. The effects on leachate quality of refuse moisture content (dry or saturated) at time of placement were also studied. Investigations were conducted on experimental refuse cells and at in-situ landfills. The investigators included: Professor Robert C. Merz of the University of Southern California; the British Ministry of Housing and Local Government; and the Department of Water Resources, Southern District.

The study at Riverside by Merz, (7) discussed in the preceding section, determined the quality of leachate from irrigated refuse. Leachate was drawn from test bin number 1 several times monthly (leachate did not form in bin number 2) and subjected to mineral and biochemical analysis. Analyses of the leachate are presented in Table 10.

Percentage composition of material leached from the refuse in test bin number 1 were calculated and are shown in Table 11. These values were based on the volumes of leachate, presented in Table 7, and corresponding analyses, presented in Table 10.

These percentages represent the 18-month study duration and are somewhat less than the total amounts that are theoretically extractable. Decomposition of carbohydrates in the form of wood and paper products occurs at a relatively slow rate. This is evidenced by the relatively constant concentrations maintained in the leachate over the last 6 to 8 months of the study.

Several studies were made by the British Ministry of Housing and Local Government⁽³⁾ to determine leachate quality under the following conditions: three small cells exposed to various

amounts of water; dry placement of refuse in a large cell exposed to rainfall only; and wet placement of refuse in a large cell with high-rate water application. The construction and operation of the cells used in the first two studies are discussed in detail in the preceding section. The test cell in the third experiment was identical to that used in the second. However, this cell was filled with water before placement of refuse. Upon placement of refuse, a condition resulted similar to that of dumping refuse in ground water. The refuse was then subjected to horizontal flow of water at a rate of about 3.4 gal./day/ft².

Leachate drawn from the three cells in the first experiment was analyzed monthly. Chemical and biochemical analyses are presented in Table 12. The consistently high level of organic carbon (a measure of the total organic matter) in cell 3, along with a relatively low BOD, indicates that a large portion of organic matter was biologically stable before leaving the refuse cell.

In the large dry refuse placement experiment, leachate was obtained after one month of operation. The leachate was analyzed several times monthly; the averages are presented in Table 13.

The third experiment (wet placement of refuse) represents the most acute condition with respect to ground water impairment. Deposited refuse was completely submerged, and horizontal flow of water through the refuse resulted in the maximum amount of leaching. Analyses of the water after passage through the refuse are presented in Table 14.

TABLE 10
CHEMICAL ANALYSES OF LEACHATE FROM REFUSE TEST BIN (7)

Mean monthly values
In parts per million

Date	pH	Total hardness (CaCO ₃)	Alkalinity (as CaCO ₃)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Total iron (Fe)
February 1953	6.28	4,660	3,800	1,460	250	1,030	865	80
March 1953	5.67	7,800	8,430	2,450	320	1,730	1,775	245
April 1953	5.95	6,050	5,760	1,870	280	1,350	1,155	235
May 1953	6.13	4,270	5,530	1,280	230	1,010	980	160
July 1953	6.00	4,300	6,790	1,340	195	1,090	1,240	100
August 1953	6.00	5,140	8,070	1,480	175	1,215	1,345	104
September 1953	6.51	3,750	5,000	960	135	840	925	120
October 1953	6.70	1,810	2,550	465	91	560	530	81
November 1953*	6.80	1,520	2,310	370	89	540	505	44
December 1953	7.25	1,220	2,220	200	98	520	465	16
January 1954	7.00	1,040	1,935	165	102	475	465	22
February 1954	7.05	1,150	2,050	153	115	525	480	27
March 1954	7.15	810	1,930	140	120	500	500	26
April 1954*	7.18	695	2,080	135	105	530	520	40
May 1954*	7.38	820	2,380	165	125	650	655	25
June 1954*	7.63	650	2,110	115	100	640	625	24

Date	Ferrous iron (Fe)	Chloride (Cl)	Sulfate (SO ₄)	Inorganic phosphate (PO ₄)	Organic nitrogen (N)	Ammonia nitrogen (N)	BOD
February 1953	15	1,515	455	13	146	51	21,700
March 1953	35	2,225	680	19	475	556	30,250
April 1953	28	1,630	415	9.2	300	740	27,730
May 1953	66	1,195	250	6.0	145	578	18,700
July 1953	9	1,475	207	2.8	176	760	16,000
August 1953	47	1,770	255	2.3	270	850	17,900
September 1953	1	1,280	190	2.0	160	530	10,890
October 1953	—	795	108	3.0	37	355	5,790
November 1953*	8	730	62	2.2	48	285	—
December 1953	—	1,065	63	5.0	29	280	455
January 1954	9	950	59	5.2	25	180	285
February 1954	9	700	54	5.5	22	195	220
March 1954	—	720	46	5.5	22	175	118
April 1954*	4	755	54	5.6	22	175	125
May 1954*	2	1,000	50	5.0	26	255	98
June 1954*	3	1,045	48	5.9	21	240	81

* One sample taken during month

TABLE 11
LEACHATE CHARACTERISTICS
UNDER CONTROLLED WATER APPLICATION (7)

Determination	Amount leached
	Percent of dry refuse weight*
Alkalinity (as CaCO ₃)**	0.78
Calcium (Ca)	0.16
Magnesium (Mg)	0.029
Sodium (Na)	0.15
Potassium (K)	0.18
Total iron (Fe)	0.019
Chloride (Cl)	0.22
Sulfate (SO ₄)	0.022
Inorganic phosphate (PO ₄)	0.0014
Organic nitrogen (N)	0.032
Ammonia nitrogen (N)	0.072
BOD**	2.54
Leached volume: 0.21 gal/lb. — 3.5 in/ft.	

* Assumed dry density of refuse, 275 lb/cu. yd.

** In equivalent terms

TABLE 12
CHEMICAL ANALYSES OF LEACHATE FROM REFUSE TEST CELLS
UNDER VARIED CONDITIONS OF WATER APPLICATION (3)
In parts per million

Month	Cell 1					Cell 2					Cell 3				
	NH ₃ (N)	NO ₃ (N)	Organic (N)	Organic (C)	BOD	NH ₃ (N)	NO ₃ (N)	Organic (N)	Organic (C)	BOD	NH ₃ (N)	NO ₃ (N)	Organic (N)	Organic (C)	BOD
1953															
Aug.	127	10.7	233	5,800	13,500	—	—	—	—	—	—	—	—	—	—
Sept.	34	6	117	1,520	—	694	10	261	7,320	12,000	—	—	—	—	—
Oct.	14	27	117	1,990	—	446	5	88	1,970	3,650	—	—	—	—	—
Nov.	450	5	167	6,700	12,500	269	4	62	2,070	3,980	—	—	—	—	—
Dec.	490	10	111	4,490	7,660	96	4	41	1,050	1,640	—	—	—	—	—
1954															
Jan.	560	13	101	4,200	7,050	92	8	30	1,500	2,460	—	—	—	—	—
Feb.	470	9	95	2,920	4,350	141	17	61	830	1,000	55	407	66	1,020	261
Mar.	195	18	75	820	204	166	27	51	450	264	44	370	69	770	65
April	80	23	55	710	156	—	—	—	—	—	—	465	75	920	—
May	17	207	41	480	93	—	—	—	—	—	28	1,300	117	1,390	191
June	4	240	33	380	36	5	143	22	190	33	5	148	53	880	31
July	3	255	41	350	28	3	60	13	210	28	5	60	67	1,420	43
Aug.	3	227	27	410	40	3	13	5	115	9	3	13	30	1,000	3

TABLE 13
CHEMICAL ANALYSES OF LEACHATE FROM REFUSE (3)
Mean monthly values in parts per million

Year	Month	Number of samples	NH ₃ (N)	NO ₃ (N)	Organic nitrogen (N)	Organic carbon (C)	Sulfate	Chloride	BOD
1954	July	5	78	57.8	10.8	125	539	---	125
	Aug.	5	265	28.5	61	1,694	441	---	3,028
	Sept.	4	127	37.0	19	314	427	---	200
	Oct.	3	289	23.3	51.4	1,110	1,146	---	1,605
	Nov.	10	537	0	120.1	3,380	1,423	---	5,645
	Dec.	8	694	0	182.2	4,710	1,321	---	7,745
1955	Jan.	9	670	0	132	3,470	898	--	5,767
	Feb.	8	668	0	101	3,244	248	1,845	5,491
	March	9	687	0	100	2,400	738	1,968	2,689
	April	7	668	0	94	1,958	231	1,987	2,534
	May	8	496	0	77	1,055	323	1,629	1,152
	June	9	553	0	77	2,494	2.2	1,577	3,965
	July	8	664	0	81	1,675	3.2	1,887	1,624
	Aug.	9	637	0	75	907	4.2	1,830	526
	Sept.	9	630	0	71	686	71.8	1,874	163
	Oct.	9	447	0	60	666	133	1,389	397
	Nov.	10	441	0	67	1,325	80	1,438	1,794
	Dec.	4	458	0	59	678	606	1,710	396
1956	Jan.	5	302	0	44	860	380	1,438	1,008
	Feb.	4	379	0	50	844	816	1,386	764
	March	4	320	0	42	394	1,826	1,382	55
	April	4	322	0	41	381	1,602	1,440	44
	May	5	355	0	50	467	856	1,763	56
	June	3	286	0	36	527	512	1,407	51
	July	5	187	0	28	341	81	1,407	38
	August	3	110	0	15	161	98	622	15
	Nov.	4	189	0	49	283	1,344	1,357	12
	Dec.	4	129	0	40	251	1,266	1,100	47
1957	Jan.	4	77	0	18	170	1,334	853	25
	Feb.	4	42	0	12	176	930	573	18

TABLE 14
CHEMICAL ANALYSES OF LEACHATE FROM REFUSE
IN THE BRITISH WET PLACEMENT STUDY (3)
In parts per million

Refuse placement period	Number of samples	Refuse placed per period (tons)	Constituent					BOD
			Sulfate	Chloride	NH ₃ (N)	Organic nitrogen (N)	Organic carbon (C)	
1955								
Sept. 8— Oct. 7	8	19.4	70	54	5.1	5.0	126	228
Oct. 8—Nov 4	8	2.4	21	41	3.2	3.0	83	147
Nov. 5— Dec. 2	8	2.5	21	39	3.4	2.5	74	126
Dec. 3—Dec. 30	6	—	38	34	2.1	1.4	43	63
1956								
Dec. 31—Jan. 27	7	37.1	369	152	34.6	10.7	597	1,088
Jan. 28—Feb. 24	5	—	274	121	16.3	5.7	318	594
Feb. 25—Mar. 23	7	—	96	54	7.8	2.9	77	124
Mar. 24—Apr. 20	5	—	71	49	3.6	2.5	52	82
Apr. 21—May 18	4	7.4	51	65	11.4	2.6	105	206
May 19—June 15	4	—	15	76	18.0	2.1	135	245
June 16—July 13	3	7.3	3	100	24.4	4.3	252	413
July 14—Aug. 10	3	10.1	10	140	47.8	6.4	410	818
Aug. 11—Sept. 7	4	—	3	128	53.6	6.9	456	975
Sept. 8—Oct. 5	4	—	5	82	42.2	4.2	147	241
Oct. 6—Nov. 22	4	—	27	78	41.0	3.2	60	50
Nov. 23—Nov. 30	4	—	53	61	25.5	2.4	19	13
Dec. 1—Dec. 28	6	21.3	306	216	102.8	9.1	210	365
1957								
Dec. 29—Jan. 25	5	—	50	152	90.8	3.4	126	233
Jan. 26—Feb. 22	4	—	19	91	45.3	2.2	73	108
Feb. 23—Mar. 22	4	—	5	78	30.5	2.3	38	74

sition of refuse in the test cell place intermittently throughout study, and the quality of leachate varied accordingly. High values of BOD, organic carbon, organic nitrogen, etc., occurred shortly after new addition of refuse to the cell and decreased steadily in between. The trends in leachate quality with respect to time are almost identical to those found in the other two experiments.

Amounts of material leached from the refuse in the large-scale dry and wet cell studies are presented in Table 15. In the wet refuse cell, applied refuse was in contact with the soluble components of the refuse for a longer time, resulting in more material leached. The amount of material leached was highest in

BOD, followed by organic carbon, chloride, and sulfate.

The results of these studies may be compared with results from the study by Merz presented previously in Table 11. BOD of the leached material was greater in Merz's study, whereas chloride and sulfate were leached in greater quantity in the British experiments. The differences can be explained by the composition of refuse used in the test cells.

Refuse used in Merz's study was typically that of Southern California, with large amounts of vegetation, paper and wood material, small amounts of garbage, and no ash. The refuse used in the British experiments contained lesser amounts of wood products, more garbage, ash in varying amounts, and

TABLE 15
MATERIAL LEACHED FROM REFUSE TEST CELLS
UNDER VARIED CONDITIONS OF WATER APPLICATION (3)

Determination	Amount leached			
	Dry refuse cell		Wet refuse cell*	
	Lbs.	Percent of dry refuse weight**	Lbs.	Percent of dry refuse weight**
BOD***	488	0.71	1,110	1.75
Organic carbon	292	0.46	612	0.97
Organic nitrogen	13	0.021	16.5	0.026
Ammonia (as N)	67.1	0.106	116	0.185
Chloride (Cl)	229	0.36	222	0.35
Sulfate (SO ₄)	151	0.24	275	0.44
Sulfide (S)	(as combined with SO ₄ above)		23.3	0.037
Period of leaching	33 months		20 months	
Leachate volume	0.14 gal./lb.		2.6 gal./lb.	

* Refuse completely submerged and subjected to a horizontal flow of water at a rate of 3.4 gal./day/sq. ft.

** Assumed dry refuse weight of 375 lb./cu. yd.

*** In equivalent terms

more noncombustibles. The result was that the refuse in Merz's study contained a higher percentage of material that was biologically oxidizable, whereas, ash, which contributes more chloride, sulfate, and other minerals, caused the higher percentages of chloride and sulfate leached in the British studies.

As part of the Department's investigation, the quality of leachate from municipal refuse in an in-situ fill was studied. The site selected was the Scholl Canyon Landfill of the County Sanitation Districts of Los Angeles County in Glendale. Three wells were placed immediately downstream of Stage I of the landfill, as shown in Figure 17.

Stage I of the Scholl Canyon Landfill is subject to rainfall and irrigation (quantities given in Chapter II) causing excessive amounts of water in the refuse, resulting in the formation of leachate. Ground water was analyzed periodically for mineral, heavy metal and BOD and COD. Results are present in Tables 16, 17, and 18. In addition two samples of leachate from the Puente Waste Disposal Landfill in the City of Industry, California, were analyzed to determine mineral and heavy metal content and oxygen demand. These analyses are presented in Table 19.

The trends of leaching established in the studies by Merz and the British are

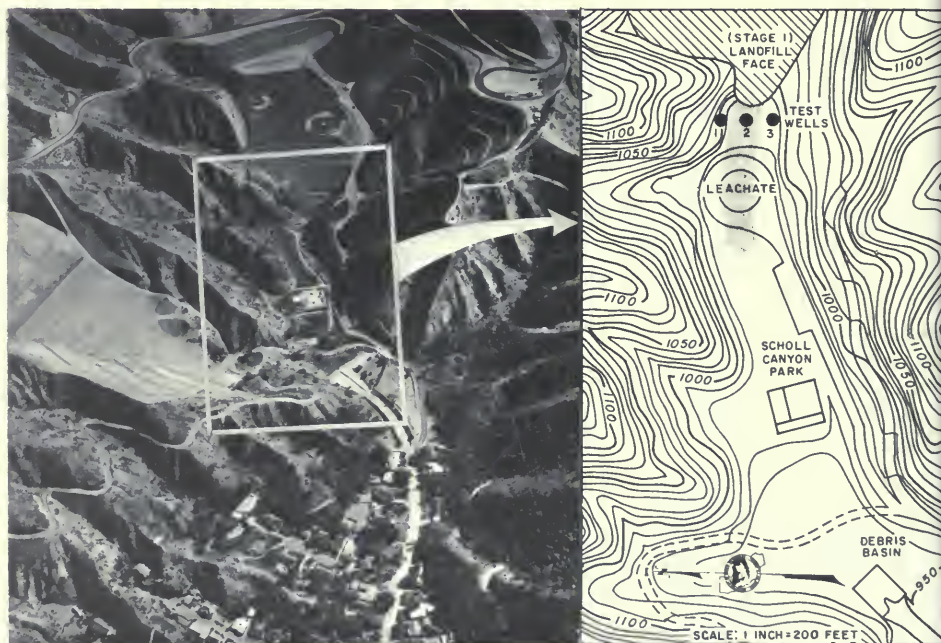


Figure 17 - TEST FACILITIES - SCHOLL CANYON LANDFILL

generally borne out by the trends found at Scholl Canyon. Calcium, magnesium, sodium bicarbonate, chloride, and total hardness were present in the leachate at levels 5 to 10 times those of ground water in the area. The absence of appreciable quantities of nitrate (the final product of the nitrogen aerobic decomposition cycle) and sulfate indicate that decomposition was proceeding anaerobically.

The difference between COD and BOD values, approximately 4,500 ppm initially, represents the portion of organic carbon present in the lea-

chate that is subject to chemical but not biological oxidation. Similar findings were observed in the third test cell of experiment number 1 in the British studies.

Results of analyses of the samples obtained at the Puente Waste Disposal Landfill, although representing only a very short period of time on the decomposition cycle, are an indication of quantities of material leached. Concentrations of material found in the leachate are well within ranges found in the studies presented in this chapter.

TABLE 16
CHEMICAL ANALYSES OF LEACHATE FROM
SCHOLL CANYON LANDFILL
In parts per million

Determination	Date sampled						
	8/2/63	12/20/63	4/20/64	7/22/64	9/3/64	2/2/65	5/13/65
H	7.4	7.2	7.2	7.1	7.8	7.2	7.1
C x 10 ⁶ @ 25° C	3000	2300	2900	3000	2250	3300	3100
Calcium	382	567	457	395	95	457	473
Magnesium	148	30	180	265	207	223	188
Sodium	90	87	88	100	98	102	115
Potassium	7.2	6.5	6.8	8	13	12	8
Bicarbonate	2014	1826	2122	2516	1259	2209	2101
Sulfate	1.0	4.8	4.8	2	6	14	10
Chloride	67	177	220	188	209	298	344
Nitrate	0.0	0.0	0.8	0.0	0.0	4.0	0.0
Fluoride	0.1	0.2	0.1	0.1	0.1	0.2	2.4
Iron	0.2	0.33	0.41	0.30	0.40	0.36	0.35
Total dissolved solids	2058	1452	2664	2496	1460	2330	2586
Total hardness (CaCO ₃)	1563	1540	1880	2075	1085	2055	1955

TABLE 17
HEAVY METAL ANALYSES OF LEACHATE FROM
SCHOLL CANYON LANDFILL
In parts per million

Constituent	Date sampled	
	7-10-63	5-13-65
Aluminum	10	< 25
Beryllium	< 2.0	< 1.3
Bismuth	< 1.0	< 0.67
Cadmium	< 5.0	< 3.3
Chromium	< 5.0	< 3.3
Cobalt	11	< 3.3
Copper	24	< 3.3
Gallium	< 20	< 13
Germanium	< 1.0	< 0.67
Iron	5.4	260
Lead	< 5.0	< 3.3
Manganese	> 200	> 1400
Molybdenum	18	6.7
Nickel	16	28
Titanium	7.8	4.7
Vanadium	40	7.3
Zinc	< 20	> 1000

TABLE 18
OXYGEN DEMAND OF LEACHATE FROM
SCHOLL CANYON LANDFILL
In parts per million

Determination	Date sampled		
	6-10-63	2-19-65	3-9-66
Biochemical oxygen demand (BOD)	1200	97	113
Chemical oxygen demand (COD)	5750	354	312

TABLE 19

MINERAL AND HEAVY METAL ANALYSES AND OXYGEN DEMAND OF LEACHATE
FROM PUENTE WASTE DISPOSAL LANDFILL*

Determination	Date sampled	
	2-13-62	3-5-62
pH	6.0	7.2
Calcium	1,340	560
Magnesium	547	455
Sodium	620	810
Potassium	340	700
Bicarbonate	3,260	5,730
Sulfate	1,370	--
Chloride	1,100	1,330
Nitrate	4.5	--
Fluoride	2.1	--
Total dissolved solids	18,154	12,530
Total hardness (CaCO ₃)	5,600	3,260
Iron	135	150
Manganese	18	13
Zinc	--	20
Lead	--	0.125
Biochemical oxygen demand	2,200	9,200
Chemical oxygen demand	4,180	9,280

All values are in parts per million except pH.

Gas

The formation of gas with respect to production and movement has been discussed in detail in Chapter III. The purpose of the following sections is to present actual production quantities and composition determined from experimentation on refuse test cells under simulated conditions of refuse disposal in landfills. Investigations of primary importance to this report were conducted by Professor Robert C. Merz of the University of Southern California, by Engineering Science, Inc., and by the Department of Water Resources.

Quantity of Gas

Theoretical production of gas was discussed in Chapter III. In the landfill environment, a number of factors, such as composition of refuse and presence of air and water, influence gas production and create results that vary from the theoretical.

In a laboratory study by Merz, (29) the above factors were introduced under experimental conditions and resulting gas production was determined.

Eight 55-gallon steel drums were used as test cells in the study. The drums were lined and coated with plastic to prevent gas leakage and were drilled to take air, water, and sample lines. In each cell, the refuse volume was 6.70 cubic feet and the density was 540 pounds per cubic yard. Refuse composition and treatment were intended to simulate conditions in a landfill. The rate of gas production varied directly with temperature of refuse, moisture content, garbage content, and amount of air present in the refuse. The composition of refuse, method of operation, and rates of gas production for each cell are shown in Table 20.

The most important single factor found to influence the quantity of gas produced was water application. Drum F, which was saturated, produced 17 cubic feet of gas, more than $2\frac{1}{2}$ times that produced in any other cell. Other cells that received water produced gas at an increased rate but always substantially lower than Drum F. Aeration of Drum D increased gas production significantly although not as much as application of water to Drum F. Minor differences in rates of production between cells operated identically can be explained by the variation in garbage content, garbage being the main refuse component that underwent significant decomposition.

Composition of Gas

The composition of gas produced under varied conditions of refuse composition, aeration, and moisture was determined by Merz,⁽²⁹⁾ as discussed in the preceding section. Analyses of samples of gas from each of the eight test cells are presented in Table 20.

The character of gas produced in each of the test cells (large percentages of CO₂ and very minor percentages of methane) indicates that primarily an

aerobic environment existed. With the exception of Drums B and F, no methane was detected, and in these, only in concentrations of less than 1 percent. Percentages of CO₂ were markedly higher in Drums E and F, treated with water and with air and water, respectively.

Experiments to determine the composition of gas produced from refuse in test cells constructed at Spadra Landfill of the County Sanitation District of Los Angeles County have been made by Merz⁽³⁰⁾ and by the Department. The site location and layout of test facilities are shown in Figure 18. The test facilities are discussed in the "Scope and Conduct of Investigation" section of Chapter I.

As the cells were constructed, half sections of 55-gallon steel drums with sampling probes were installed within the refuse and sampling probes were placed in the adjacent earth.

The methods of operating the test cells and analyses of the gas obtained from them are summarized in Table 21.

The decomposition of refuse in cells 1 through 5 was primarily anaerobic. The presence of significant percentages of oxygen at the 6-foot level in cells 3, 4, and 5 indicates partial aerobic decomposition, accounting for the abnormally low methane production.

In cell 6, decomposition occurred aerobically for the most part, as was intended. CO₂ production ranged from 5.8 to 41.9 percent by volume. However, the presence of methane, found in percentages up to 11.3 percent by volume, indicates that a portion of the refuse was decomposing anaerobically.

The effects of water application on gas production from the test cells were also studied. With the exception of cell 1, which was initially

TABLE 20
DATA FROM GAS PRODUCTION STUDY BY MERZ

DRUM	A	B	C	D	E	F	G	H
COMPOSITION OF REFUSE								
Grass, dry weight (lbs.)	15.	15.	31.	31.	31.	31.	31.	31.
Wet weight	34.5	34.5	67.0	67.0	67.0	67.0	67.0	67.0
Paper, dry weight	81.	81.	46.	46.	46.	46.	46.	46.
Wet weight	89.7	89.7	49.6	49.6	49.6	49.6	49.6	49.6
Garbage, dry weight	3.	3.	4.	4.	4.	4.	4.	4.
Wet weight	13.8	13.8	17.4	17.4	17.4	17.4	17.4	17.4
OPERATION								
METHOD	No soil, air, or water added	No soil, air, or water added	Soil added* No air or water added	Soil* and air added	Soil* and air added	Soil added* saturated with water	Soil* air, and water added	Soil*, air, and water added
Initial moisture, percent of dry weight	85	85	70	70	70	70	70	70
Peak temperature reached, Deg. F.	109	109	108 **	107	108	108	100***	111
Elapsed time (days)	411	393	364	353	383	394	175	352
GAS PRODUCTION								
Cubic ft. of gas produced	2,540	3,574	3,388	5,705	6,577	17,005	3,716	4,696
Elapsed days	684	684	667	653	663	666	666	666
Cubic ft. of gas per pound of refuse	0.026	0.036	0.042	0.070	0.081	0.210	0.046	0.058
CO ₂ , percent by volume (min.-max.)	22-42	40-78	31-65	44-75	53-82	45-98	16-68	55-78
N ₂ , percent by volume (min.-max.)	54-77	21-60	33-69	24-55	17-44	0.43-51	31-78	20-39
H ₂ , percent by volume (min.-max.)	0-0.80	0-0.83	0-0.87	0.16-3.5	0.01-4.0	0.01-13.1	0-9.0	0.17-8.7
CH ₄ , percent by volume (min.-max.)	0-0	0-0.81	0-0	0-T	0-0	0-0.06	0-0	0-0

* Five pounds of soil added to provide soil bacteria normally found in landfill.

** First 428 days only; 120 degrees with external heating after 565 days..

*** First 230 days only; 120 degrees with external heating after 282 days.

TABLE 21
GAS PRODUCTION TEST AT SPADRA*

CELL	METHOD OF OPERATION	Percent moisture (dry wt.)	Refuse density in place (lb/cu. yd.)	Sampling depth (feet)	Gas components, percent by volume							
					CO ₂		N ₂		O ₂		CH ₄	
					Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1	Refuse placed continuously to depth of 18 feet. 2-foot earth cover. Refuse saturated.	80.1	960	6	56.0	33.4	28.9	5.7	5.3	0.0	54.1	16.7
				15	75.0	37.4	20.4	0.0	4.9	0.0	55.7	20.3
2	Refuse placed in 4-foot layers separated by 1-foot earth layers, with a 1-foot earth cover.	43.5	845	6	33.4	25.4	72.3	45.4	10.2	0.1	28.1	0.0
				15	50.8	33.0	57.9	21.5	1.8	0.0	37.8	1.5
3	Refuse placed in 4-foot layers separated by 1-foot earth layers, with a 1-foot earth cover.	29.4	710	6	49.8	17.0	82.0	46.4	5.9	0.2	1.2	0.0
				15	36.0	22.4	74.1	57.1	6.4	0.0	2.3	0.2
4	Refuse placed continuously to depth of 18 feet. 2-foot earth cover. Minimum compaction	51.9	550	6	37.2	10.4	80.3	52.3	11.7	0.0	9.6	0.0
				15	40.6	23.9	74.5	43.1	4.8	0.0	14.7	0.5
5	Earth mixed with refuse at ratio of 1:2.2. Mixture placed continuously to depth of 18 feet; 2-foot earth cover.	34.8	695	6	38.0	19.0	74.1	41.4	5.0	0.0	22.5	0.0
				15	48.1	32.5	62.8	37.2	1.5	0.1	24.8	1.1
6	Cell above ground surface on rubble to admit air all around. Refuse placed continuously to depth of 18 feet; 2-foot earth cover.	89.8	755	6	41.9	5.8	91.7	46.5	25.9	0.0	11.3	0.0
				15	39.0	9.1	84.6	47.7	10.6	0.3	9.4	0.2

* Study duration was 873 days.

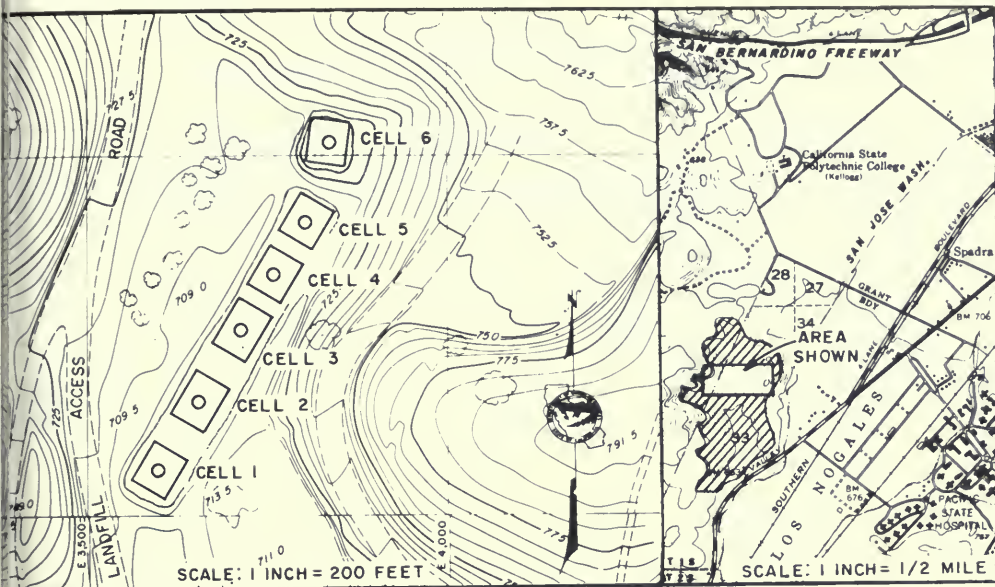


Figure 18 - FACILITIES - SPADRA EXPERIMENTAL TEST SITE

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

saturated, and cell 3, to which no water was added, the test cells received various amounts of water, applied about two-thirds of the way through the study.

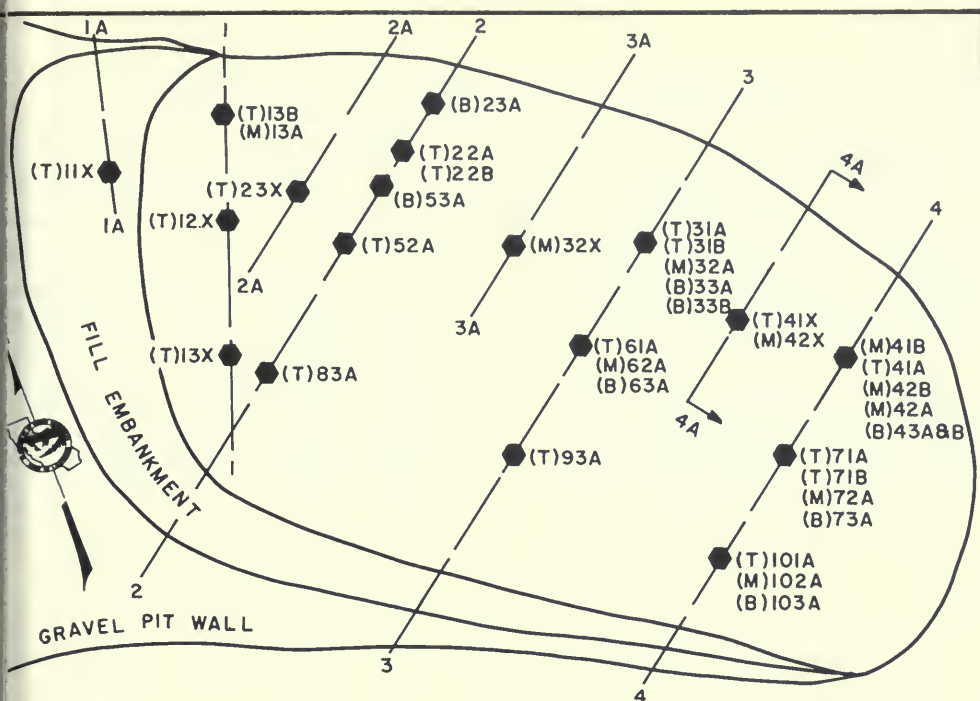
The primary effect of water application on the refuse was the increased production of methane, up to 25 percent by volume of the gas produced. Free oxygen was depleted. In cell 6, which was constructed to allow maximum aeration, the applied water drained relatively rapidly, permitting "reaeration" and the return of at least partial aerobic conditions, as opposed to the other irrigated cells, which remained anaerobic through the duration of the study.

Gas production at several of the Spadra test cells was also studied by the Department in conjunction with Merz. Analyses of samples obtained from test cells 2 through 5 in the access well and the adjacent undisturbed soil are summarized in Table 22. These results are a positive indication of movement of gas from the refuse into the soil and also of the magnitude of CO_2 leaving the refuse, with concentrations up to 60 percent by volume at the sampling probes. In addition, analyses of samples of the soil atmosphere at each probe location prior to refuse placement are presented as a means of comparing normal atmosphere composition with that of the waste gas.

TABLE 22
COMPOSITION OF GAS IN ACCESS WELLS
AND IN EARTH ADJACENT TO THE SPADRA TEST CELLS

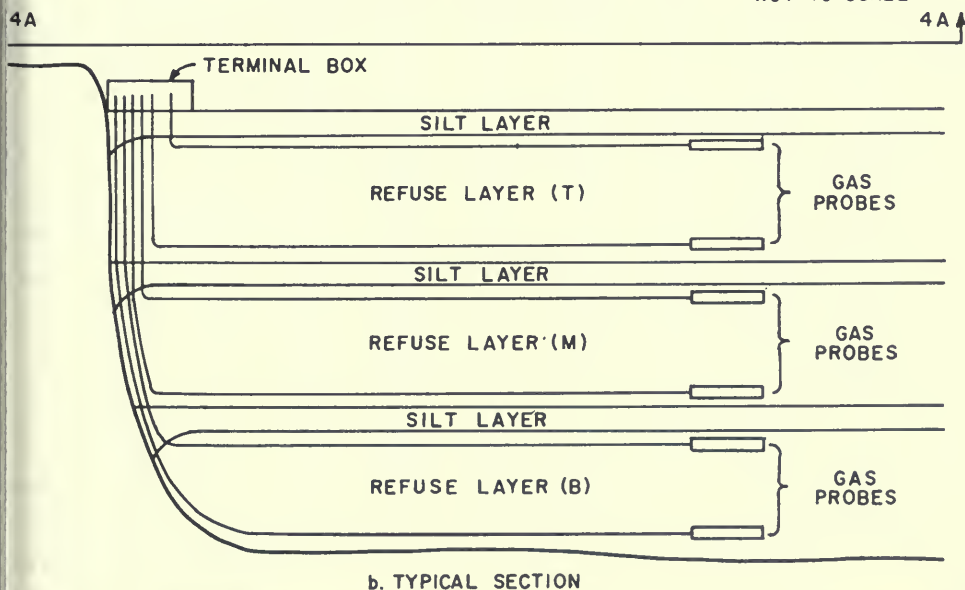
Cell number	Date sampled	Elapsed time (days)	Composition of gas — percent by volume											
			Access Wells				Side-3-feet into earth				Bottom—3-feet into earth			
			CO ₂	N ₂	O ₂	CH ₄	CO ₂	N ₂	O ₂	CH ₄	CO ₂	N ₂	O ₂	CH ₄
2	10-14-60*	—	19.6	67.0	13.4	0.0	0.1	79.4	20.5	0.0	0.1	79.3	20.6	0.0
	12-19-60	—	45.8	51.4	2.8	0.0	24.8	65.9	9.3	0.0	36.8	61.5	1.7	0.0
	1-17-61	21	28.3	62.7	8.5	0.5	16.8	70.5	12.7	0.0	38.0	60.9	1.1	0.0
	2-23-61	58					44.7	54.2	0.9	0.2	39.5	58.9	0.9	0.7
	3-16-61	79					26.4	64.5	8.9	0.2	41.9	54.8	2.2	1.1
	6-21-61	176	35.7	55.4	5.0	3.9	23.7	67.8	7.9	0.6	33.9	58.0	5.4	2.7
	9-22-61	269					28.2	66.1	4.6	1.1	28.9	61.9	5.1	2.5
	1- 3-62	372					39.9	56.5	2.1	1.5	22.9	67.1	8.9	1.1
	8-14-63	595					25.4	72.0	2.6	—	27.0	68.8	4.2	—
	8-24-64	970					7.0	73.0	20.0	—	28.0	69.0	3.0	—
3	10-14-60*	—					0.1	79.4	20.5	0.0	0.1	80.1	19.8	0.0
	1-17-61	5	27.8	67.6	4.6	0.0	—	—	—	—	27.2	70.0	2.8	0.0
	2-23-61	42	22.7	71.2	6.1	0.0	28.2	70.2	1.6	0.0	28.3	70.3	1.4	0.0
	3-16-61	63	17.9	73.8	8.3	0.0	26.3	71.4	2.3	0.0	25.4	70.2	4.2	0.2
	6-21-61	160	25.0	73.1	1.9	0.0	19.4	74.5	6.1	0.0	21.2	73.0	5.8	0.0
	9-22-61	253					25.1	73.2	1.7	0.0	26.9	71.9	1.2	0.0
	1- 3-62	356					30.7	66.2	3.1	0.0	33.8	64.8	1.4	0.0
	8-14-63	579					21.2	75.6	3.2	—	21.2	75.6	3.2	—
	8-24-64	954					20.0	62.0	18.0	—	30.0	60.0	10.0	—
4	10-14-60*	—					—	—	—	—	0.1	79.3	20.6	0.0
	2-23-61	34	24.4	67.6	7.5	0.5	31.3	64.8	3.1	0.8	21.7	69.6	7.6	1.1
	3-16-61	55	16.8	70.1	12.8	0.3	34.4	61.0	3.6	1.0	34.4	60.8	3.6	1.2
	6-21-61	152	7.0	76.4	16.3	0.3	17.9	72.0	9.7	0.4	27.1	69.1	2.6	1.2
	9-22-61	245					8.3	75.6	15.6	0.5	15.0	73.2	11.0	0.8
	1- 3-62	348					29.8	64.6	4.6	1.0	25.1	67.6	6.4	0.9
	8-14-63	571					1.8	79.0	19.2	—	0.4	79.8	19.8	—
	8-24-64	946					31.0	63.0	6.0	—	—	—	—	—
5	10-14-60*	—					0.1	79.5	20.4	0.0	0.1	79.6	20.3	0.0
	2-23-61	13	34.0	58.3	7.7	0.0	47.4	47.2	5.4	0.0	59.9	37.9	2.1	0.1
	3-16-61	34	41.3	55.8	2.4	0.5	48.8	48.4	2.7	0.1	50.2	46.3	3.1	0.4
	6-21-61	131	18.4	70.7	9.6	1.7	18.5	69.2	11.6	0.7	20.9	66.9	11.3	0.9
	9-22-61	224					11.3	67.2	9.2	1.3	21.5	66.1	10.5	1.9
	1- 3-62	327					46.0	50.4	0.8	2.8	37.2	58.2	3.3	1.3
	8-14-63	550					7.0	77.0	16.0	—	8.6	75.4	16.0	—
	8-24-64	925					3.0	80.0	17.0	—	19.0	70.0	11.0	—

* Soil atmosphere before refuse placement.



a. PLAN VIEW — EXPERIMENTAL FILL

NOT TO SCALE



b. TYPICAL SECTION

Figure 19 — GAS SAMPLING LOCATIONS WITHIN REFUSE — AZUSA EXPERIMENTAL LANDFILL

(17)

The composition of gas produced from refuse at the Azusa Experimental Landfill was observed by Engineering-Science, Inc.(11) The construction of the test facilities was discussed in Chapter I. Probe locations for sampling of gas in the three layers of refuse are shown in Figure 19. Summaries of analyses of gas samples obtained from these probes during the period from March 1962 through June 1964 are presented in Table 23.

The decomposition trends within the landfill, aerobic or anaerobic, are evidenced best by the concentrations of oxygen present throughout the refuse. Higher percentages of free

oxygen indicate aerobiosis, as is the case primarily in the top layer closest to the soil cover and the air reservoir. Partial aerobiosis also exists along the outer extremities of the landfill, which are in direct contact with the adjacent soil atmosphere.

However, as one proceeds into the fill, the amount of available free oxygen decreases markedly, and anaerobic conditions are found. This is evidenced by an increasing methane content toward the interior and lower reaches of the fill. Also, as the results presented in Table 23 indicate, the CO₂ concentration increased in the same manner.

TABLE 23
COMPOSITION OF GAS FROM DECOMPOSING REFUSE WITHIN
THE AZUSA EXPERIMENTAL LANDFILL

Refuse layer	Probe No.	Section location	Composition of gas — percent by volume							
			CO ₂		O ₂		H ₂		CH ₄	
			Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Top	11X	1	21.8	1.0	20.0	1.1	2.5	1.7	0.4	0.1
	12X	1	24.3	0.3	19.9	1.0	2.3	0.0	0.3	0.1
	13X	1	24.3	0.2	19.9	1.0	2.2	1.1	0.3	0.2
	22A	2	54.5	19.0	2.1	0.8	3.3	0.0	2.5	0.1
	22B	2	54.6	19.8	0.8	0.0	3.8	3.0	0.3	0.2
	52A	2	52.7	22.1	1.2	0.0	3.4	0.0	1.5	0.1
	83A	2	47.6	16.5	8.3	0.0	2.7	0.0	2.8	0.0
	31A	3	60.9	22.2	0.5	0.0	3.0	0.0	0.7	0.1
	31B	3	60.8	20.3	0.8	0.0	4.6	2.4	0.2	0.2
	61A	3	58.0	17.0	4.4	0.0	3.5	0.0	1.4	0.0
	93A	3	58.1	21.2	1.6	0.0	4.9	0.0	2.2	0.0
	41B	4	57.8	3.7	17.2	0.1	2.4	0.0	0.2	0.0
	41A	4	62.7	23.0	3.9	0.0	5.7	0.0	3.0	0.1
	71A	4	70.5	7.7	13.5	0.1	3.3	0.0	1.4	0.0
	71B	4	71.2	11.4	10.6	0.1	2.6*	—	0.1*	—
	101A	4	48.1	6.6	15.3	0.2	4.7	0.0	0.7	0.0
	13B	1	24.5	2.9	17.9	1.1	2.3	1.1	0.3	0.1
	23X	Between 1 & 2	41.5	21.2	0.9	0.0	3.1	0.0	0.5	0.2
	41X	Between 3 & 4	40.2	12.2	10.2	0.1	3.5	0.0	0.8	0.0
Center	32A	3	69.7	11.7	8.3	0.1	5.9	0.0	4.7	0.0
	62A	3	69.4	23.3	2.9	0.0	4.3	0.0	2.8	0.0
	42B	4	60.6	24.3	2.7	0.1	3.4	3.2	0.4	0.1
	42A	4	58.6	20.5	1.2	0.0	4.6	0.0	5.4	0.1
	72A	4	67.9	25.0	4.2	0.0	6.5	0.0	9.0	0.1
	102A	4	66.7	20.0	6.2	0.1	6.1	0.0	4.8	0.0
	13A	1	52.4	1.4	19.4	0.2	3.6	1.6	0.2	0.0
	32X	Between 2 & 3	68.8	28.0	0.9	0.0	5.7	4.5	0.4	0.2
	42X	Between 3 & 4	66.8	26.4	6.4	0.0	5.6	3.4	0.4	0.1
Bottom	23A	2	72.0	25.4	0.4	0.0	7.3	0.0	11.6	0.0
	53A	2	89.4	20.8	7.9	0.0	14.1	0.0	29.6	0.1
	33A	3	70.1	23.5	1.8	0.0	8.0	0.0	7.4	0.1
	33B	3	70.4	24.8	0.4	0.0	5.7	1.9	3.3	0.3
	63A	3	73.2	27.8	1.2	0.0	6.8	0.0	6.1	0.1
	43B	4	58.0	26.5	1.2	0.0	5.0	0.0	4.8	0.0
	43A	4	59.8	22.6	1.8	0.0	5.9	0.8	6.1	0.0
	73A	4	71.1	29.4	4.1	0.0	6.4	0.0	10.0	0.0
	103A	4	74.4	21.1	7.5	0.1	5.7	0.0	10.7	0.2

One analysis

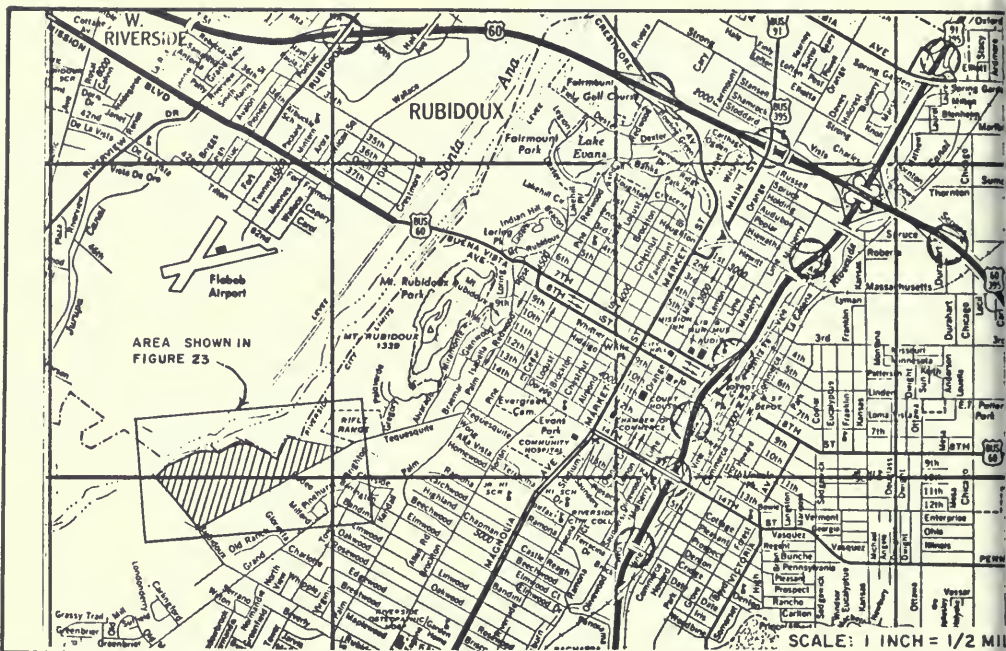


Figure 20. - AREA MAP - RIVERSIDE LANDFILL

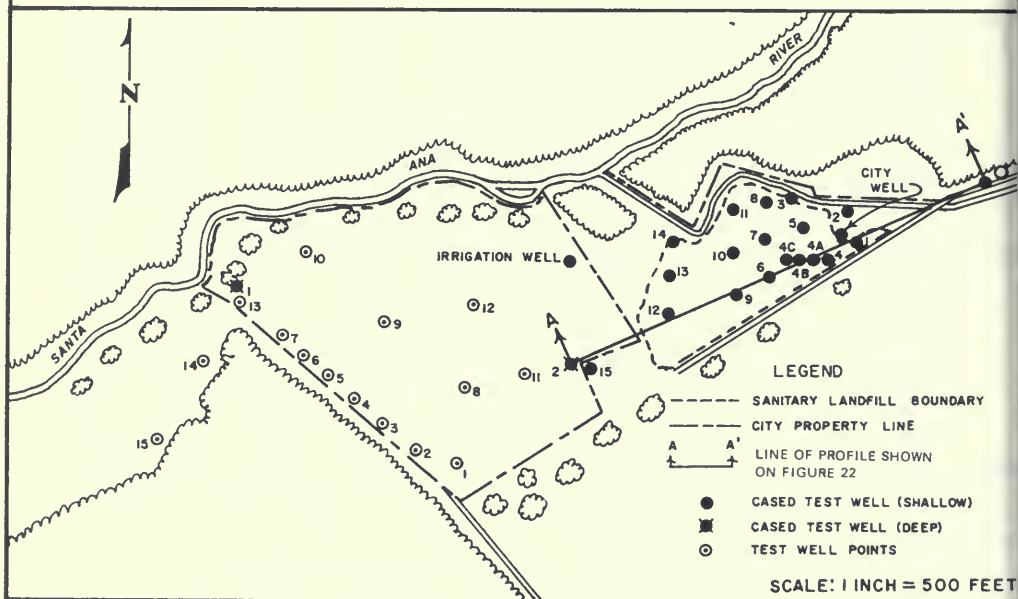


Figure 21. - LOCATION OF TEST WELLS - RIVERSIDE LANDFILL

CHAPTER V. EFFECTS OF DECOMPOSITION WASTE PRODUCTS ON GROUND WATER

The movement of decomposition products after their formation within the refuse is inevitable under current refuse disposal practices. Gas rises into the atmosphere and, together with any leachate produced, permeates into the underground. From the standpoint of ground water impairment, the situation is of primary concern. Gases entering the atmosphere diffuse and mix until they are unable to be identified as a source or effects. Diffusion and dispersion of gases moving underground is limited by the composition and grain size distribution of the soil and rock material, by the solubility of the gases, by the density of the gases relative to air and water, and by the moisture content of the soil.

Resulting effects range from minor to gross impairment, with considerable impact on the mineral quality of the receiving ground waters. The degree of impairment depends primarily on the character and quantity of the pollutants.

Although an impairment potential exists wherever waste materials are deposited on land, there are few instances where actual effects are documented at existing monitoring facilities.

Effects of Leachate on Ground Water

A discussion of the effects of leachate on ground water requires consideration of the refuse materials versus the quality of the receiving water. A portion of the organic and inorganic matter contained in the refuse can be extracted prior to decomposition by leaching. Additional material will be released in time as decomposition proceeds. The degree of water quality impairment will depend on the rate of leaching and the

amount of leachable material available.

Bacterial decomposition of organic matter leached from the refuse requires satisfaction of the biochemical oxygen demand. This oxygen demand is satisfied by the free oxygen in the receiving water. A sizable organic load will deplete the free and dissolved oxygen supply rapidly, thus anaerobic conditions will prevail. The extent of this condition will depend on the rate of stabilization by reaeration and mixing with water containing dissolved oxygen and by the rate of ground water movement.

Whereas organic leachate will become stabilized with time, mineral leachate is almost always permanent. However, the degree of impairment can be lessened by dispersion and mixing with waters of higher quality, and can be eliminated if a condition of basin outflow exists where the mass of degraded water moves to a body of lower quality water, e.g., the ocean. The degree of impairment can also be lessened and possibly eliminated by ground water extraction, with subsequent surface transportation to a lower quality or degraded body of water.

In general, the effects of leachate on the receiving water include increases in the concentrations of minerals present, resulting in a lowering of quality that in turn affects the suitability of the water for beneficial use. These effects will be discussed in the following sections as quality changes with respect to the Drinking Water Standards, U. S. Public Health Service, 1962, (26) Irrigation Water Quality Criteria, and general hardness criteria, all presented in Attachment 3 of this report.

Several instances of ground water impairment by leachate from a landfill have been reported, the most notable being at Riverside, California.

Riverside Landfill

The Riverside landfill is owned and operated by the City of Riverside. A study of this landfill was conducted by Professor Robert Merz of the University of Southern California. (7)

The Riverside sanitary landfill lies to the west of the city, along the south-east bank of the Santa Ana River, as shown in Figure 20. Details of the site and the landfill boundary are shown in Figure 21.

The Riverside landfill was put into operation in the early 1920's. Material

accumulated prior to 1938 was removed by the flood of that year. The disposal site was operated as a burning type until 1948, when it was converted to a sanitary landfill. Refuse was deposited in trenches cut to the ground water level. As a result, some refuse was deposited directly into ground water

Preliminary investigation by Merz determined the direction of ground water flow (southwest) and the relationship of the ground water table to the landfill bottom. Locations of test wells are shown in Figure 21. A profile through the landfill and a number of test well (plan view in Figure 21) showing the extent of refuse deposition, ground water level, and underlying aquifers is in Figure 22.

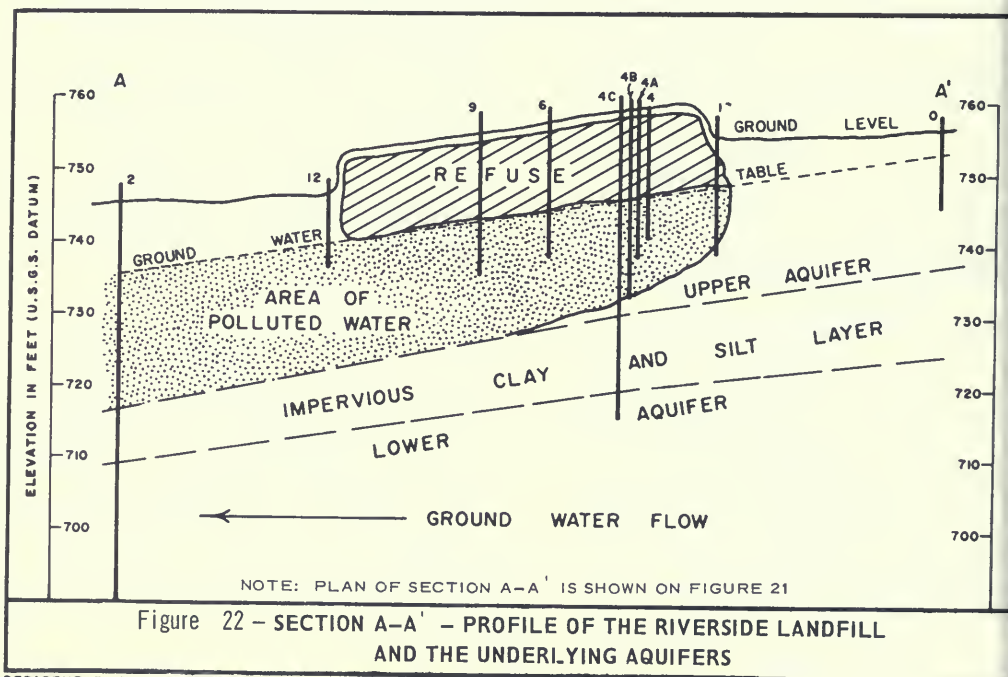


TABLE 24
AVERAGES OF ANALYSES OF WATER FROM THE
21 CASED WELLS JULY 1, 1952 - JUNE 30, 1954
In parts per million

termina- tion	Well No.										
	0	1	2	3	4	4a	4b	4c	5	6	7
Carbon dioxide	7.21	6.83	7.35	7.24	6.98	7.12	6.94	7.24	6.88	7.20	7.24
Total hardness (CaCO ₃)	20	90	44	45	187	138	167	35	178	56	83
Calcium	311	628	409	552	912	1046	683	305	513	567	436
Magnesium	277	398	324	378	955	740	582	277	607	399	424
Sodium	95	144	118	176	226	244	194	89	140	150	119
Potassium	17	55	28	36	87	102	59	16	30	51	34
Total iron	75	280	125	142	426	652	222	71	134	168	139
Chloride	4.7	9.5	5.6	7.2	28	40	24	4.9	16	9.7	12.5
Sulfate	0.01	1.8	0.47	1.25	6.7	4.3	6.5	0.05	6.9	6.1	8.5
Phosphate, inorganic	73	390	144	225	500	773	288	78	164	217	132
Organic nitrogen	74	280	126	167	178	577	240	67	42	198	68
Ammonia nitrogen	0.06	0.06	0.08	0.12	0.19	0.05	0.05	0.05	0.50	0.10	0.34
NO ₃ -N	0.31	0.81	0.44	0.48	1.8	0.66	0.53	0.12	1.33	0.75	0.65
NO ₂ -N	0.11	0.51	0.38	0.46	1.51	1.04	0.83	0.22	5	0.66	2.3
DO*	2.3	8.9	2.0	1.5	38	59	57	0.60	52	8.6	5.3
DO (calculated)	523	1400	780	1000	2055	2990	1390	510	910	1060	770
Well No. (continued)	8	9	10	11	12	13	14	15	City well	Irrigation well	
Carbon dioxide	7.15	7.21	6.89	6.92	6.95	7.35	7.08	7.25	7.59	7.57	
Total hardness (CaCO ₃)	71	78	193	135	175	103	125	48	7.7	10	
Calcium	631	567	679	613	780	605	1175	600	263	273	
Magnesium	486	522	726	520	850	488	390	433	221	212	
Sodium	184	148	191	182	215	177	355	178	82	86	
Potassium	49	49	48	37	48	41	62	37	13	15	
Total iron	153	174	151	137	150	170	320	165	41	45	
Chloride	7.6	20	44	20	21	14	14	9.0	3.4	3.9	
Sulfate	11	8.0	16	5.3	9.9	12.6	16	0.26	0.00	0.00	
Phosphate, inorganic	235	227	197	208	300	258	620	263	47	48	
Organic nitrogen	169	96	90	109	60	137	480	115	46	75	
Ammonia nitrogen	0.06	0.20	2.1	0.47	0.70	0.65	1.6	0.55	0.02	0.08	
NO ₃ -N	0.89	0.74	1.28	0.61	0.97	0.9	0.9	0.4	0.10	0.10	
DO*	0.58	2.2	5.9	4.6	1.3	1.07	1.7	0.96	0.19	0.14	
DO (calculated)	6.8	7.5	7.8	3.8	5.4	9.6	9.3	0.97	1.9	1.2	
DO (calculated)	1120	1055	1195	1040	1255	1120	2150	1065	390	410	

One sample per well for the study period

The second step in the investigation was to determine the effects on the quality of ground water underlying and immediately adjacent to the landfill. A total of 23 permanent cased wells were located for sampling purposes. These are shown in Figure 21 and each is symbolized by a solid circle. Use of these wells was as follows: well 0, located 1,000 feet upstream from the fill, was used as a control; well 15, located about 900 feet downstream, was used to detect lateral movement of pollutant; wells 4a, 4b, and 4c, located within the fill, were used to detect vertical movement of pollutant; and the remaining wells were used to determine degree and areal extent of impairment.

Samples were collected and analyzed periodically during the investigation. The results were averaged and are presented in Table 24. In general, the constituents in the ground water that

increased significantly were those found to be leached in greatest quantities in the controlled experiments discussed in Chapter IV. BOD, chloride, sodium, and sulfate showed the greatest increases - 26, 10, 9, and 8 times, respectively, over the concentrations found in the unaffected control well 0. Total hardness and alkalinity also showed considerable change - more than a threefold increase over that of the control well.

Water samples from well 4c, which penetrated the lower aquifer underlying the landfill site (Figure 22), showed no increase in mineral and biological constituents. This indicates a high degree of competency of the clay layer separating the aquifers, which acted as a barrier to the downward movement of leachate. Water samples from well 15, located downstream, showed considerable increases in minerals and BOD, indicating lateral migration of the degraded mass of water.

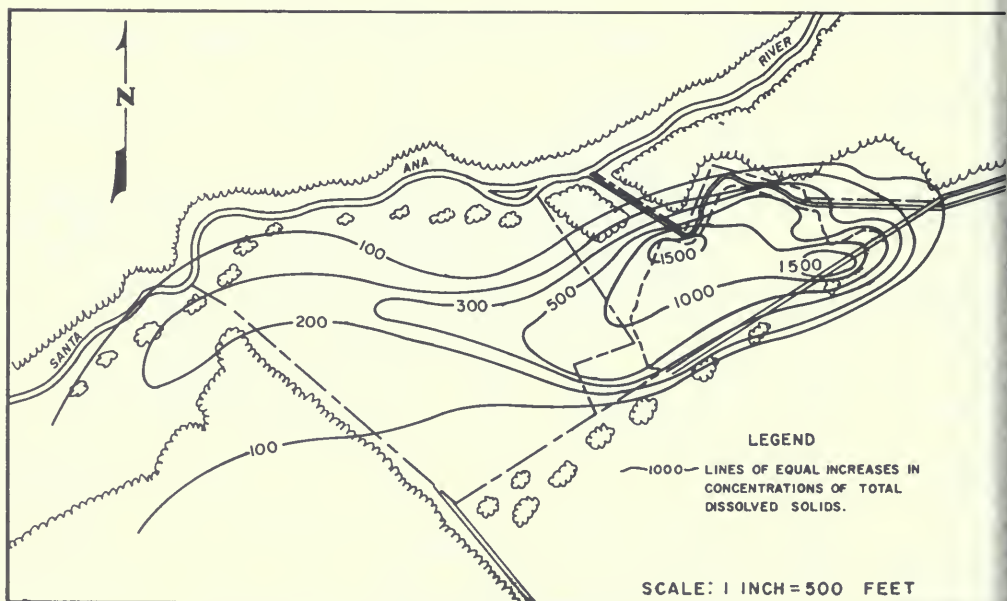


Figure 23 - EXTENT OF GROUND WATER IMPAIRMENT - RIVERSIDE LANDFILL

final part of the investigation was determination of the extent of movement of ground water downstream of the fill. To accomplish this objective, 15 well points were placed west of the fill in the direction of ground water flow. The locations of well points are shown in Figure 21.

Samples of samples obtained from the well points during the study were averaged and the results are presented in Table 25. In general, the ground water at well points showed significant increases in mineral constituents, hardness and alkalinity. However, the increases were considerably less than those in the ground water directly underlying the fill. Sulfate showed the greatest change, with a threefold increase. Other constituents increased to maximum values of about one and one-half times normal. Well point 13, located 4,000 feet downstream, showed the

greatest influence from the refuse-derived leachate. Well point 15, located nearly 1 mile downstream, was the most distant point of quality measurement and showed an overall constituent increase of about 31 percent. The areal extent of ground water impairment is shown in Figure 23 as lines of equal increases in TDS concentrations above normal level.

A comparison of upstream, underlying, and downstream ground water quality is presented in Table 26. Profiles of concentrations of total dissolved solids, hardness, and chloride in the ground water upstream from, downstream from, and underlying the landfill, are depicted in Figure 24. In general, constituents increased considerably to a maximum in the area underlying the landfill at the point of leaching and then decreased gradually toward normal, facilitated by advection, diffusion, and dispersion.

TABLE 25
AVERAGES OF ANALYSES OF GROUND WATER SAMPLES
OBTAINED FROM WELL POINTS

Concentration	Well point number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Temperature	7.36	7.40	7.20	7.15	7.14	7.11	7.06	7.17	7.12	7.26	7.47	7.07	7.14	7.25	7.38
Hardness (CaCO ₃)	306	333	395	376	383	389	396	408	449	445	426	382	530	430	345
Alkalinity as CaCO ₃	258	256	319	339	312	320	331	336	345	338	383	298	378	343	298
Calcium	89	93	115	109	115	120	120	123	139	133	136	123	141	130	113
Magnesium	22	23	23	26	23	22	24	22	22	22	24	17	33	23	18
Sulfate	89	86	98	80	83	81	82	72	60	67	84	45	80	103	118
Chloride	6.8	6.6	8.5	8.4	9.8	11	12	7.7	12	13	8.0	7.5	12	11	11
Total dissolved solids	122	123	121	84	96	89	76	83	63	58	103	70	69	88	122
Calcium chloride	68	56	99	82	93	104	125	101	127	140	94	103	189	152	103
Calcium sulfate	0.55	0.68	1.1	1.1	1.4	0.61	0.39	0.61	0.73	1.0	0.20	0.47	0.76	0.82	1.6
Calcium bicarbonate	0.08	0.02	0.08	0.10	0.06	0.06	0.07	0.10	0.12	0.14	0.08	0.09	0.23	0.18	0.24
Sulfate bicarbonate	1.0	1.1	2.6	1.8	2.1	1.8	1.6	0.89	4.9	4.2	1.1	0.72	1.1	1.7	2.7
Calcium chloride (calculated)	525	560	680	610	640	635	656	620	670	670	690	560	775	740	690

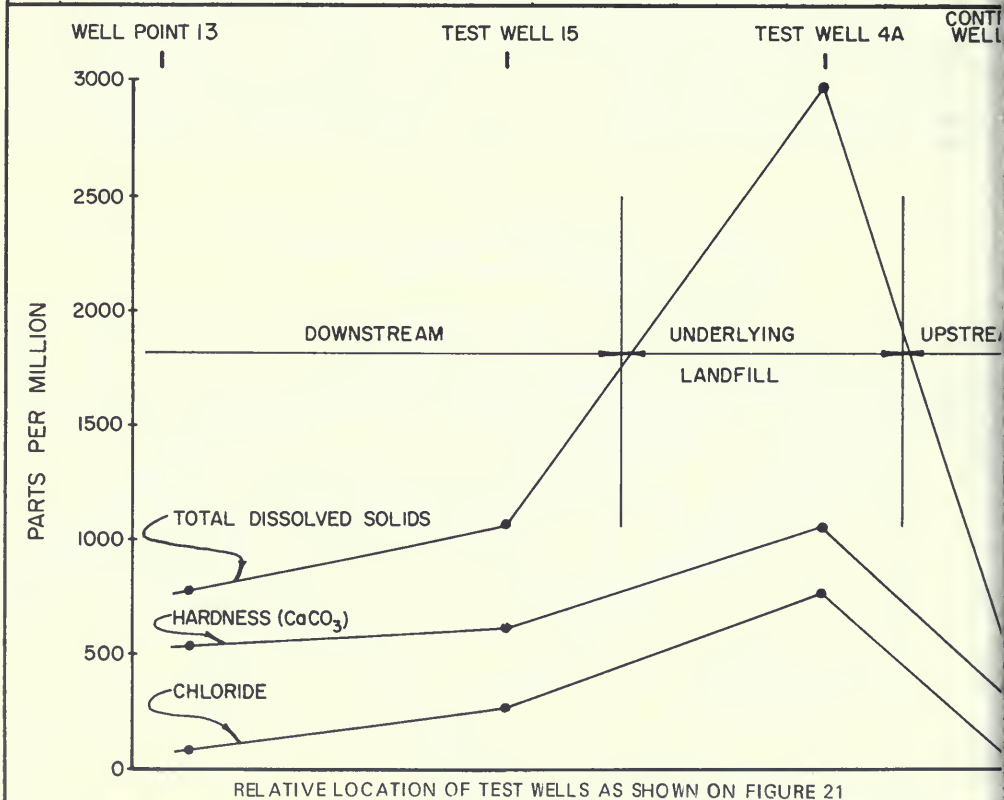
Values in parts per million except pH.

TABLE 26

COMPARISON OF UPSTREAM, UNDERLYING, AND DOWNSTREAM GROUND WATER QUALITY

DETERMINATION*	CONTROL WELL 0	TEST WELL CASED NO. 4A	TEST WELL CASED NO. 15	WELL POINT NO. 13
TOTAL HARDNESS	311	1046	600	530
ALKALINITY	277	740	433	378
CALCIUM	95	244	178	141
MAGNESIUM	17	102	37	33
SODIUM	75	652	165	80
POTASSIUM	4.7	40	9	12
CHLORIDE	73	773	263	69
SULFATE	74	577	115	189
TDS (CALCULATED)	523	2990	1065	775

*ALL RESULTS IN PPM

Figure 24 - PROFILES OF CERTAIN CONSTITUENT CONCENTRATIONS
IN GROUND WATER - RIVERSIDE LANDFILL AREA

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

und waters in the vicinity of the landfill site can be classified by quality according to the various standards previously discussed in this chapter. With respect to the USPHS Drinking Water Standards, the recommended limit of 500 ppm of total dissolved solids was generally exceeded, even in normal ground water, and the recommended limit of 250 ppm of chloride and sulfate was exceeded in the area underlying and immediately downstream from the landfill. According to the Irrigation Water Quality Criteria, upstream ground water was Class 1 in nature, underlying ground water was Class 2 to Class 3, and downstream ground water was Class 1 to Class 2. All ground waters in the area can be characterized as being very hard, with the highest degree of hardness found in the water underlying and immediately downstream from the landfill.

Other Cases of Impairment

Ground water at Kresfeld, Germany, and the effects of refuse deposited in a gravel pit were studied. Private and municipal water supply wells, located from one-half to 4 miles downstream, showed significant increases in total hardness, chloride, and sulfate. Hardness increased about 700 ppm while chloride increased about 200 ppm. Small rises in iron, manganese, and ammonia were also observed. The impairment persisted for about 18 years before normal conditions again prevailed.

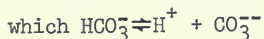
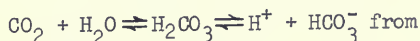
A similar occurrence was reported at Birrshof, Germany. Refuse deposited in a gravel pit extending below the ground water table produced leachate that impaired ground water at least 300 feet downstream. Hardness increased from 200 ppm to about 1,150 ppm. This impairment persisted over 10 years.

Other instances of ground water impairment by leachate derived from refuse deposits have been reported. Each instance is characterized by substantial

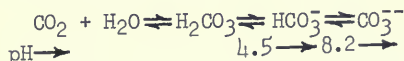
increases in total dissolved solids, total hardness, chloride, and sulfate, and also by lengthy duration. It is also recognized that many such cases have been, are, and will be unnoticed and therefore not documented. There is also the possibility of mistaken identity as to the source of impairment. For example, a German experience is reported where plotted contours of increases in biochemical oxygen demand indicated the source of impairment to be an unsewered residential area, but plotted contours of TDS, chloride, and hardness increases pointed to an old refuse disposal site.

Effects of Gas on Ground Water

The three principal effects of carbon dioxide on ground water are increased hardness, corrosivity, and acidity. These effects are functions of the carbon dioxide combined with bicarbonates and carbonates present in the receiving ground water, plus the pH of the water. These are bound in the complex equilibria of the following reactions: (24)



The pH of the receiving water influences, and is influenced by, the ratios of carbon dioxide to bicarbonate ions and bicarbonate ions to carbonate ions at equilibrium. The solution of calcium carbonate and the increase of carbon dioxide in the solution will change the pH. The concentration of carbon dioxide is controlled by the equilibrium reaction:



Water containing practically no HCO_3^- and CO_3^{--} ions will have a pH of 4.5 or less, thus causing acidity. Water containing almost no CO_3^{--} ions, but containing HCO_3^- and CO_2 , will have a pH of 8.2 or less. Depending on the relative amount of CO_2 and HCO_3^- , water may be acidic, neutral, or alkaline. Water con-

taining CO_3^{2-} , HCO_3^- , and CO_2 will have a pH value above 8.2, causing alkalinity and hardness.

Acidity is usually caused by the presence of free carbon dioxide; mineral acids, such as sulfuric, or weakly dissociated acids, such as carbonic, that affect the buffering action; and salts of strong acids and weak bases. Excessive acidity (excessive free carbon dioxide) increases the aggressiveness of a water, thereby accelerating the corrosion of iron and steel, promoting the solution of lead and zinc, and increasing the solvent (corrosion) action on calcium carbonate in concrete. Free carbon dioxide in excess of 20 ppm will attack iron, steel, and concrete rapidly enough to require protective measures. (10)

Alkalinity is caused primarily by the presence of carbonates, bicarbonates, and hydroxides. Bicarbonates represent the major form of alkalinity. Although alkalinity is not considered detrimental to humans, highly alkaline waters are unpalatable and objectionable to consumers. Alkalinity is, however, detrimental to many industrial processes, especially those involving the production of food and beverages and has been limited by recommended threshold values ranging from 30 to 250 ppm. (10)

Hardness is caused by bivalent metallic ions (calcium, magnesium, and ferrous iron) that react with soap to form precipitates. Excessive concentrations of free carbon dioxide will cause dissolution of carbonate compounds from soil and rock formations. Water containing carbonates and bicarbonates of calcium and magnesium will form a scale consisting of calcium carbonate and magnesium hydroxides (temporary hardness) when evaporated or heated. This becomes increasingly critical in hot water heaters and piping systems. Recommended hardness limits range up to a maximum of 80 ppm. The end result of the presence of excessive free carbon dioxide is that it will dissolve until its concentration in the water is in equilibrium

with the partial pressure of CO_2 in the atmosphere right above the water. Solubility of CO_2 up to 1720 ppm can be attained only if there is one atmosphere of CO_2 in contact with the water table.

A number of cases of ground water impairment by carbon dioxide have been documented by various investigators. Of primary importance are studies by the Department at Azusa and Monrovia.

Azusa Experimental Landfill

The Azusa experimental landfill was the subject of extensive gas movement and ground water pollution monitoring studies. It was discussed in Chapter I of this report.

Gas movement studies were made by Engineering-Science, Inc. (11) to determine horizontal and vertical gas movement rates in soil adjacent to the refuse and also to determine relative quantities of gas passing to the atmosphere and to the soil. Results of these studies were presented in Chapter III. However, several findings are extremely significant to the ground water pollution study made by the Department at this site. These are vertical velocities of carbon dioxide movement ranged from an initial high of 0.8 foot/day to 0.22 foot/day under reduced gradients; the quantity of CO_2 passing to the atmosphere was approximately twenty times that passing into the soil; quantities of CO_2 passing into the atmosphere ranged from 1,750 pounds/acre/day to 470 pounds/acre/day, also depending upon the CO_2 gradient between fill and atmosphere.

As an indication of the downward movement of carbon dioxide in the soil underlying the landfill, carbon dioxide concentrations were plotted with respect to time for sampling probes at various depths in well No. 1, located at the center of the landfill. These plots are shown in Figure 25. The rate of gas movement is governed by the gradient of CO_2 concentration, which is indicated by decreasing CO_2 concen-

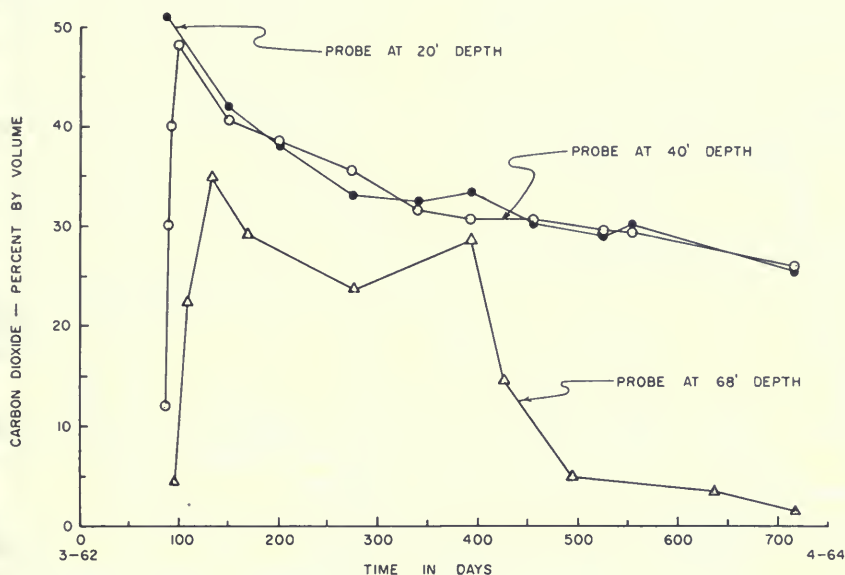


Figure 25.—CARBON DIOXIDE AT VARIOUS DEPTHS IN SAMPLING WELL NO. 1—AZUSA EXPERIMENTAL LANDFILL

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

tations with distance from the refuse landfill), in this case, depth below the landfill. Following an initial time of about 90 days, CO₂ bloomed about 300 days, reaching and maintaining a concentration of about 30 percent by volume. Thereafter, CO₂ concentrations at the 68-foot depth rapidly decreased to below 5 percent by volume and then stabilized.

The amount of gas produced can be determined by multiplying the gas production rate of 0.032 cubic foot per pound of weight of household or municipal refuse (determined by Merz in a laboratory study discussed in Chapter IV) by the weight of refuse in the landfill, which is 5,225,000 pounds (19,000 cubic yards x 275 pounds/cubic yard). This results in a total production of 167,200 cubic feet of gas.

Applying the ratio of gas passing to the atmosphere to gas passing to the soil, as determined by Engineering-Science, Inc., indicates that approximately 8,000 cubic feet of gas, primarily CO₂, will enter the soil, and part of it will eventually reach the ground water. Rates of gas movement reported by Engineering-Science were determined under dry soil conditions.

The addition of water to the soil by irrigation or rainfall will enhance the diffusion of CO₂ into the waters percolating to the receiving water.

In conjunction with Engineering-Science, Inc., the Department conducted a monitoring program to determine the effects of carbon dioxide on the underlying, or receiving, ground waters. The program consisted of placement of three test

wells at various distances downstream from the fill and the establishment of a network of sampling wells in the areas adjacent to the landfill. The locations of these wells are shown in Figure 26.

The three test wells were used as monitors of the effect of carbon dioxide, and the area wells were used to establish background or natural quality of the ground water.

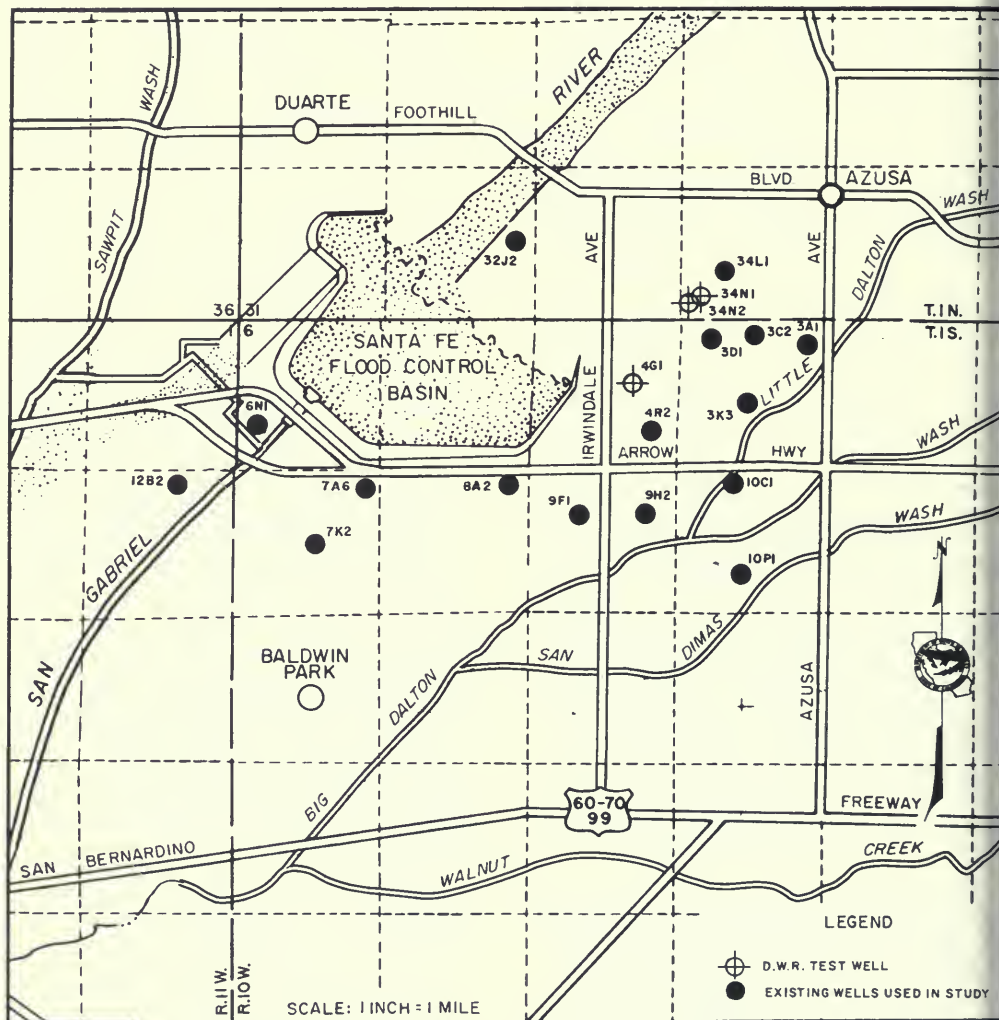


Figure 26 - WELL LOCATION MAP - AZUSA EXPERIMENTAL LANDFILL AREA

areal network of background wells canvassed several times during the course of this investigation to obtain ground water samples for standard mineral analysis and for field determination of free carbon dioxide content. Results of these mineral analyses are presented in Table 40 of Attachment 4 of this report.

The three test wells, wells Nos. 1N/10W-34N1 and 1N/10W-34N2 monitored carbon dioxide derived from the experimental landfill, while well No. 1S/10W-4G1 monitored carbon dioxide derived

from the large landfill owned and operated by the Azusa Rock and Sand Co. Water samples from these wells were obtained at regular intervals and subjected to standard mineral analysis, a summary of which is presented in Table 27. Complete mineral analyses are presented in Attachment 4, Table 43. Field determinations of free CO₂ were made at each sampling time, and the results are presented in Table 28.

Based on an average vertical velocity for CO₂ movement of 0.22 foot per day

TABLE 27
SUMMARY OF MINERAL ANALYSES OF
GROUND WATERS AT TEST WELLS - AZUSA
(January 1963 through May 1965)

Constituent	Test well					
	1N/10W-34N1		1N/10W-34N2		1S/10W-4G1	
	Low	High	Low	High	Low	High
pH	7.5	8.2	7.5	8.2	8.1	8.1
C.C. x 10 ⁶ @ 25° C	345	540	440	534	393	541
Calcium	31	67	47	75	42	74
Magnesium	9	32	11	27	6.0	24
Sodium	12	15	8	15	14	20
Potassium	3.0	4.2	1.0	4.0	3.0	5.4
Carbonate	0	0	0	0	0	0
Bicarbonate	120	235	212	253	168	283
Sulfate	15	35	19	31	13	39
Chloride	8.9	20	11	21	13	28
Nitrate	17	30	20	35	3.6	30
Fluoride	0.1	0.4	0.2	0.4	0.1	0.4
Boron	0.05	0.19	0	0.12	0.02	0.25
Total dissolved solids	200	356	276	386	246	310
Total hardness (CaCO ₃)	139	231	207	247	164	238

TABLE 28
FREE CARBON DIOXIDE IN GROUND WATER AT
TEST WELLS - AZUSA
In parts per million

Date	Well number		
	1N/10W-34N1	1N/10W-34N2	1S/10W-4G1
January 14, 1963	7	--	--
March 12, 1963	--	8	9
July 25, 1963	12	11	10
September 25, 1963	13	10	12
February 13, 1964	12	9	10
July 7, 1964	8	11	11
August 10, 1964	10	10	12
September 11, 1964	10	12	11
October 8, 1964	12	12	10
May 10, 1965	76	16	120
May 26, 1965	32	24	88
June 25, 1965	20	16	96
July 25, 1965	16	12	36
September 20, 1965	12	12	20
February 16, 1966	11	11	16

in soil, as determined in the studies by Engineering-Science, Inc., and an overall depth to ground water of 200 feet, carbon dioxide would require about 2.5 years to reach ground water. However, as infrequent as rainfall may be in Southern California, it played a significant role in speeding up the pro-

cess, because there is a definite correlation between the occurrence of significant rainfall and the appearance of free CO₂ in the ground water. Mean seasonal precipitation for the five-year period from 1960 to 1965 is depicted as isohyetal lines in Figure 6 of Chapter II. Monthly precipitation

res for the study duration at L.A. B.D. Raingage 406-C, located near Azusa Experimental Landfill, are presented in Table 29.

for a significant concentration of carbon dioxide had been built up in the soil, heavy rains occurred in April 1965. Field determinations of free CO₂ in the ground water at the wells reflected the effect of the rains for several months. The results of field determinations of free CO₂ are presented in Table 28 and are plotted with respect to time in Figure 27.

The average concentration of free carbon dioxide in the natural ground waters was 120 ppm. Ground water at well No. 1N/10W-1, located about 100 feet downstream

from the small experimental landfill, showed an increase in free CO₂ of about seven to eight times normal, but it decreased to the normal level in about three months. Ground water at well No. 1N/10W-34N2, located about 200 feet downstream from the experimental fill, showed a twofold increase in free CO₂. The significantly lower level of free CO₂ in well No. 1N/10-34N2 indicates that a large amount of CO₂ diffused in the water between the two test wells. Ground water at well No. 1S/10W-4G1, located approximately 1,000 feet downstream from the large Azusa Rock and Sand Co. landfill, showed an increase in free CO₂ of about 12 times normal to 120 ppm. Free CO₂ at this well persisted at levels around 90 ppm for approximately three months before declining to the normal level.

TABLE 29
MONTHLY PRECIPITATION AT RAINGAGE 406-C
WEST AZUSA
In inches

Month	Water year		
	1962-63	1963-64	1964-65
October	0.23	0.50	0.25
November	0.02	3.32	1.94
December	0.12	0.00	1.87
January	0.73	2.30	0.91
February	4.24	0.09	0.27
March	2.26	2.71	1.39
April	2.01	1.08	7.48
May	0.00	0.07	0.18
June	0.09	0.21	0.10
July	0.00	0.00	0.74
August	0.04	0.00	0.00
September	2.22	0.00	0.67

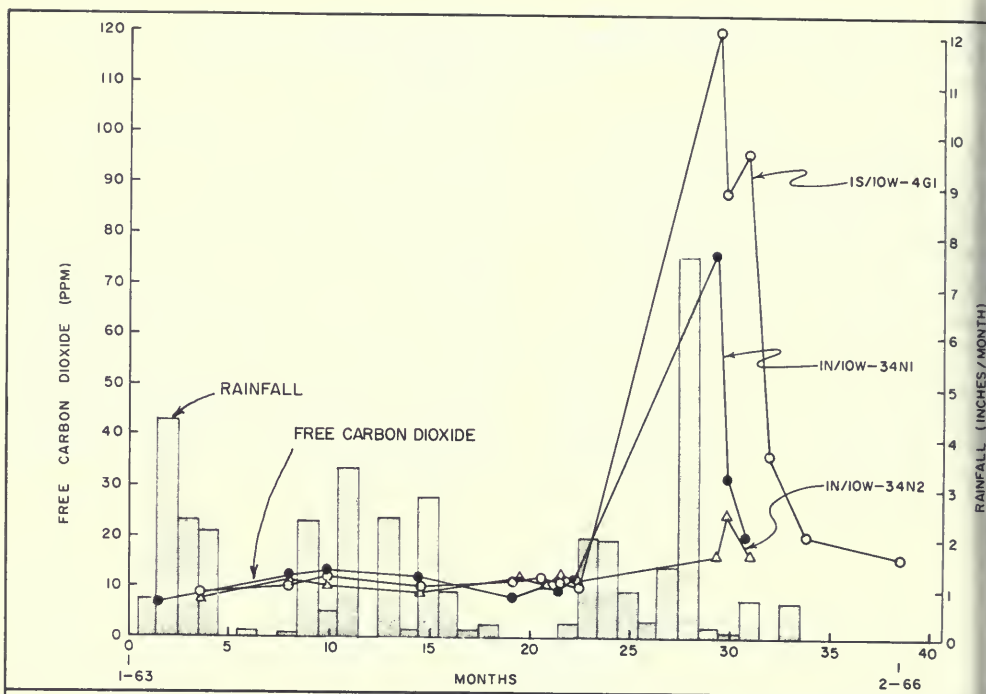


Figure 27.—RAINFALL AND FREE CARBON DIOXIDE IN GROUND WATER—AZUSA EXPERIMENTAL LANDFILL

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

During the time in which this condition existed, all water samples obtained from the three test wells exhibited objectionable turbidity, color, and odor, characteristic of samples of leachate obtained at the Scholl Canyon landfill test facilities. Colors ranged from green to brown, and odors were those of garbage (decomposing food stuffs) and oil and grease (hydrocarbons).

Slight increase of hardness and alkalinity occurred, primarily as a result of carbon dioxide. This indicates the lack of extensive carbonate deposits in the sediments underlying the Azusa site. Mineral constituents in all three test wells remained constant, indicating that inorganic water quality impairment did not occur.

Mayflower Landfill

An outstanding example of ground water pollution derived from refuse decomposition occurred at the Mayflower Landfill in Monrovia. (4) The areal detail are shown in Figure 3.

The pollution problem was discovered early 1958, when tastes and odors developed within the water service area the Mayflower Well (1S/11W-2N1), which is owned and operated by the Southern California Water Company. The Mayflower Well is located about 1,000 feet north west of the dumpsite. Due to the seriousness of this ground water impairment the Southern California Water Company

contacted the Los Angeles Regional Water Quality Control Board. In turn, the Board, recognizing the need for collection of data to establish new criteria for safe refuse disposal, contracted with the Department of Water Resources to investigate the pollution occurrence. (4)

The field investigation of the "Mayflower" incident was conducted in three phases. Phase 1 included the determination of water quality variation with respect to time in the Mayflower Well and the drilling of three test wells to determine the extent of ground water pollution. Phase 2 consisted of collection of water quality data on typical ground waters in the vicinity of the Mayflower Well. Phase 3 consisted of placement of well points in the alluvium adjacent to the landfill to determine areal distribution of gases.

The locations of the three test wells drilled during Phase 1 are shown in Figure 28. During the drilling, gas samples were collected at 20-foot intervals to determine migration of carbon dioxide from the landfill. Analyses of the gas samples are presented in Table 30. Test well No. 2, located within the landfill, showed the greatest concentration of CO_2 , with a maximum value of 45.3 percent by volume at the 80-foot level (approximately 50 feet below the base of the landfill). The maximum concentration of CH_4 (44.9 percent by volume) was also found in test well No. 2 at the 20-foot depth (within the landfill).

Following completion of the test wells, water samples were obtained and subjected to mineral analysis. Results of

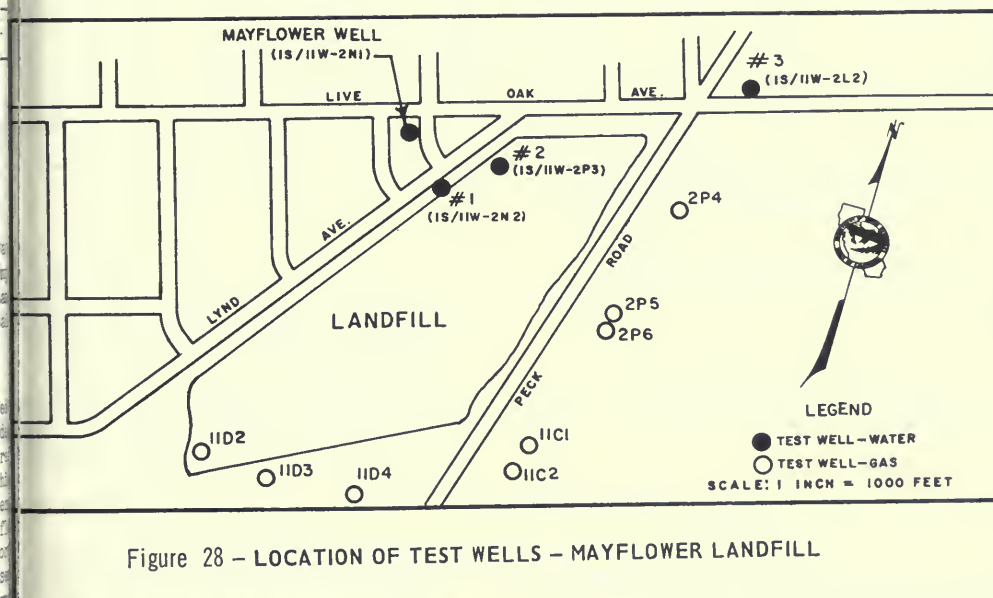


Figure 28 - LOCATION OF TEST WELLS - MAYFLOWER LANDFILL

TABLE 30
COMPOSITION OF GAS IN TEST WELLS
MAYFLOWER LANDFILL

Well number	Date sampled 1960	Sample depth*	Gases in percent by volume				
			Oxygen	Nitrogen	Carbon dioxide	Methane	Hydrogen sulfide
1S/11W-2L2 (Test Hole # 3)	4-27	20	21.5	78.5	0.03	0.0	0.0
	4-28	40	9.7	80.5	9.5	0.0	0.0
	4-29	60	6.4	78.2	15.4	0.0	0.0
	4-30	80	4.1	78.7	17.0	0.2	0.0
	5- 2	96	1.5	73.5	23.7	1.3	0.0
1S/11W-2N2 (Test Hole # 1)	4-12	20	1.8	52.0	28.6	17.6	0.0
	4-12	40	2.8	58.1	26.2	12.9	0.0
	4-14	60	1.2	58.4	29.8	10.6	0.0
	4-14	80	1.1	52.7	32.2	14.0	0.0
	4-15	100	10.1	59.3	19.3	11.3	0.0
1S/11W-2P3 (Test Hole # 2)	4-19	20	1.7	9.9	43.5	44.9	0.0
	4-20	40	12.0	61.4	15.4	11.2	0.0
	4-20	60	3.0	57.6	24.9	14.5	0.0
	4-21	80	1.9	30.9	45.3	21.9	0.0
	4-21	96	2.7	34.3	40.8	22.2	0.0

*Sampled in soil atmosphere (above ground water).

the analyses are presented in the following tabulation:

	Test well No.		
	1	2	3
Alkalinity	300	480	545
CO ₂ as CaCO ₃	152	670	425
Total hardness	377	489	663
Cl	26	43	48
pH	7.0	6.5	6.8

All values in ppm except pH.

Ground water at all three test wells contained significant concentrations

of carbon dioxide, which resulted in large increases in bicarbonate and hardness. Although well No. 3 is actually upstream from the landfill, spreading of surface waters in the adjacent river channel caused a reversal of the ground water gradient, allowing water containing carbon dioxide to migrate in that direction.

A study of water quality variation in the Mayflower Well was also conducted during Phase 1. During the

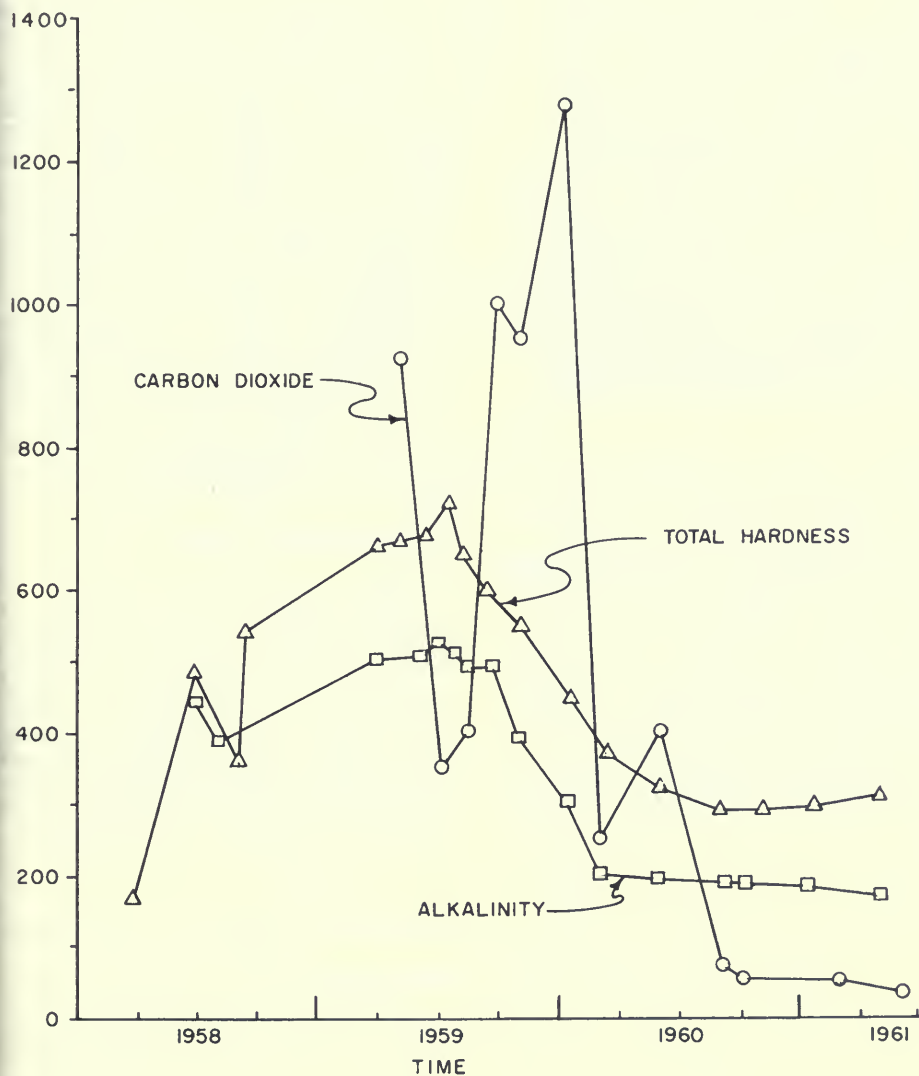


Figure 29. - CARBON DIOXIDE, TOTAL HARDNESS, AND ALKALINITY
IN GROUND WATER AT THE MAYFLOWER WELL

investigation (February 1958-June 1961), ground water samples were obtained periodically and subjected to mineral analysis. Complete results of these analyses are presented in Table 41 of Attachment 4 of this report. Carbon dioxide content, total hardness, and alkalinity, as determined by these analyses, are plotted with respect to time in Figure 29. Carbon dioxide reached a maximum level of about 1,250 ppm in January of 1960, and then decreased to the normal level of 30 ppm after eight months. Total hardness more than doubled to a maximum value of about 710 ppm and then steadily decreased to normal (approximately 300 ppm). Alkalinity increased 3-1/2 times to a high of 520 ppm before declining to the normal level (approximately 150 ppm).

Phase 2, conducted in conjunction with Phase 1, consisted of a water quality survey of selected wells to determine overall quality of ground waters in the area. Locations of the selected wells are shown in Figure 30. Analyses of water samples obtained from these wells are included in Table 42 of Attachment 4. Results of these analyses indicate that the ground waters in the vicinity of the Mayflower Landfill are of excellent mineral quality suitable for all established beneficial uses. Normal levels of carbon dioxide, total hardness, and alkalinity as CaCO_3 are 30, 250, and 150 ppm, respectively.

The normal level of free CO_2 is 8 to 10 ppm.

Phase 3 consisted of jetting eight wells into the zone of aeration of the alluvium adjacent to the landfill. Well point locations are shown in Figure 21. Gas samples obtained from these well points were analyzed for carbon dioxide, methane, nitrogen, and oxygen. Results of the gas analyses are presented in Table 31. An evaluation of the results indicates that a slight increase in carbon dioxide occurred at the well point locations, with the exception of well point No. 1S/11W-11D2, located within the landfill at the extreme downstream edge. The carbon dioxide concentration at that location was found at a high of 54.9 percent by volume. Methane, which was generally absent at most well point locations, reached a maximum of 5.5 percent by volume at this well point.

Need for Future Studies

Still unanswered are questions on direction and rate of dispersion of gases in the zone of aeration, direction and rate of absorption of gases in ground water, and the amount of gases necessary to cause pollution. Until answers to these and similar questions are known, it is not possible to make a true evaluation of the degree of impairment that gases (especially carbon dioxide) would have on ground water.

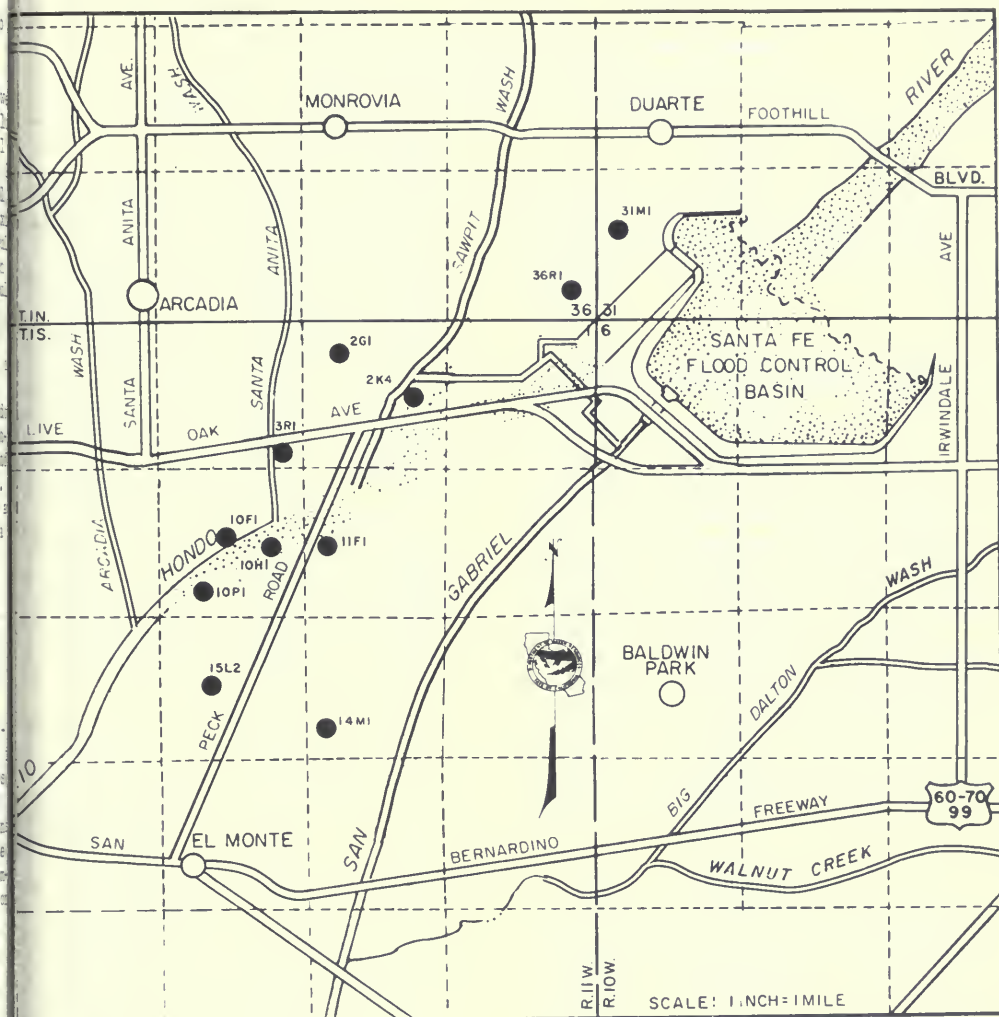


Figure 30. - WELL LOCATION MAP - MAYFLOWER LANDFILL AREA

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

TABLE 31
COMPOSITION OF GAS IN ALLUVIUM ADJACENT TO THE
MAYFLOWER LANDFILL

Well number	Date sampled	Composition of gas, percent by volume			
		Oxygen	Nitrogen	Methane	Carbon dioxide
1S/11W- 2P4	7-19-60	17.1	80.6	0.0	2.3
	8- 9-60	15.8	80.5	0.0	3.8
	6-20-61	18.6	78.9	0.0	2.6
	9-21-61	20.4	79.6	0.0	0.0
	1- 4-62	20.4	79.5	0.0	0.1
1S/11W- 2P5	7-19-60	14.7	77.2	0.0	8.1
	6-20-61	20.7	79.3	0.0	0.0
	9-21-61	21.0	79.0	0.0	0.0
	1- 4-62	21.2	78.7	0.0	0.1
	8-13-63	20.6	79.4	0.0	0.0
1S/11W- 2P6	8-13-63	18.4	78.6	0.0	3.0
1S/11W-11C1	7-19-60	18.9	78.9	0.0	2.2
	8- 9-60	19.9	78.7	0.0	1.4
	6-20-61	19.2	79.1	0.0	1.7
	9-21-61	20.9	78.2	0.0	0.9
	1- 4-62	21.1	78.8	0.0	0.0
	3-19-62	20.9	79.1	0.0	0.0
	8-13-63	17.0	81.0	0.0	2.0
1S/11W-11C2	9-21-61	20.6	77.7	0.0	1.7
	1- 4-62	21.9	78.0	0.0	0.1
	3-19-62	6.7	61.9	0.0	21.8
	8-13-63	19.2	79.0	—	1.8
1S/11W-11D2	7-19-60	2.2	38.8	4.1	54.9
	8- 9-60	3.2	46.9	4.7	45.2
	9-21-61	10.2	63.5	5.5	20.8
	1- 4-62	21.5	78.4	0.0	0.1
	8-12-63	8.6	66.4	—	25.0
1S/11W-11D3	7-19-60	21.8	77.8	0.0	0.4
	8- 9-60	21.2	78.7	0.0	0.1
	6-20-61	20.3	79.4	0.2	0.0
	9-21-61	18.0	71.8	5.4	4.8
	1- 4-62	21.1	78.6	0.0	0.3
	8-12-63	20.4	79.6	—	0.1
1S/11W-11D4	7-19-60	20.8	79.2	0.0	0.0
	8- 9-60	20.4	79.6	0.0	0.0
	6-20-61	11.2	64.8	4.6	19.4
	9-21-61	21.2	78.7	0.0	0.1
	1- 4-61	21.0	79.0	0.0	0.0

CHAPTER VI. PLANS FOR PROTECTION OF GROUND WATER

Sanitary landfill should be designed as a system, with prime consideration given to materials to be deposited, site selection, construction and operation techniques, and utilization of the completed fill, all of which weigh heavily on the degree of protection afforded area ground waters. Also, though they are not major issues in this report, the relevant atmospheric pollution problems and public health and safety problems should be considered.

Classification of Waste Materials

As a guide to prescribing requirements for disposal of waste materials at solid waste disposal sites, such materials have been separated into the following three general classifications:

Group 1. General Industrial Wastes with Significant Water Pollution Potential.

E.g., liquid and/or soluble industrial wastes, and toxic industrial ashes.

Group 2. Household and Commercial Refuse and Rubbish.

E.g., empty tin cans, metals, paper and paper products, cloth and clothing, wood and wood products, lawn clippings, sod, shrubbery, hair, hide, bones, small dead animals, roofing paper and tar paper, garbage, and ashes (except toxic industrial ashes).

Group 3. Solid, Inert Wastes.

E.g., earth, rock, gravel, concrete, asphalt paving fragments, glass, plaster and plaster board, manufactured rubber products, steel mill slag, clay and clay products, and asbestos shingles.

The above list is not intended to be complete but rather an indication of the type of waste within each classification.

Site Selection and Classification

With respect to surface and ground water pollution, the most important factors governing landfill site selection and classification are the physical characteristics of the environment surrounding the site. These characteristics, i.e., geology, hydrology, and topography, determine the degree of protection a particular site affords, thus dictating the type of refuse to be deposited. Also, in certain cases, the placement of an artificial barrier against refuse-derived gas and liquid prior to refuse placement will modify the degree of protection afforded and thus affect the type of refuse that can be deposited.

A classification system for landfill sites based on the above characteristics, including the use of artificial barriers, and on various types of refuse has been developed by the Department. The classification system consists of three general classes of sites, with corresponding groupings of types of refuse that can be deposited in each without serious threat of ground water impairment. It is recognized that the system presented is based on studies of sites in Southern California and may require modification to make it applicable to various geologic, hydrologic, and topographic conditions throughout the State.

Class I.

Waste disposal sites designated as Class I provide the maximum degree of protection for ground waters. This is accomplished by physical restriction of all gas and liquid wastes to the site proper.

Corresponding materials suitable for safe disposal in Class I sites are Groups 1, 2, and 3 wastes.

Geology. Landfill sites that are entirely underlain by nonwater-bearing geologic formations can be designated as Class I. In this case, geologic formations act as physical barriers to the lateral and downward movement of gaseous and liquid wastes produced by decomposing refuse in the landfill.

In determining how much this type of site protects ground water, an important consideration is the presence of fractures in the surrounding rock formations that may permit movement of liquid wastes from the landfill. These fractures should be pressure-grouted to ensure complete restriction of wastes to the site.

Hydrology. As previously defined, a Class I waste disposal site is not hydraulically continuous with an underlying ground water body.

Topography. Topographic characteristics to be considered in landfill site classification are the drainage tributary to the site and the surface drainage from the site. Requirements for Class I designation include diversion of all surface runoff from areas tributary to the site, generally by lined channels or drains along the perimeter of the landfill, and restriction of all surface drainage from the site. The last requirement is of prime importance because contact with liquid and solid wastes in the landfill could render drainage or overflow from the site as great an impairment hazard as the original wastes.

Since topography can generally be changed by grading or earth moving, it is not considered a controlling factor in Class I site selection. When a site is geologically and hydrologically suitable for Class I designation, it should be so designated, with the modifications for diversion of tributary runoff stipulated.

Class II

Landfill sites designated as Class II provide protection to ground waters against impairment. The amount of protection is determined primarily by the assimilative capacity of receiving waters; that is, their ability to absorb waste materials but remain suitable for beneficial use. Beneficial use, then, establish a monetary value for receiving waters and determine their assimilative capacity by virtue of quality requirements, thus dictating site selection, materials to be deposited, and necessary modifications to provide required protection.

Corresponding material suitable for safe disposal in Class II sites are Groups 2 and 3 wastes.

Sites generally considered for Class II designation are the canyon, gravel or borrow pit, and open area. A canyon landfill site, which is underlain to a large extent by rocks with low transmissibility, provides a high degree of protection for ground waters. The pit and area landfill sites provide much less protection, depending on their geologic, hydrologic, and topographic characteristics. However, with appropriate modifications, such as artificial barriers, and with proper operation, these sites can provide the degree of protection necessary for safe disposal of Group 2 wastes.

Geology. Sites that are underlain by nonwater-bearing rocks but have lateral continuity with ground water basins, typified by canyon landfill sites, are

ates that are underlain by both water-bearing and nonwater-bearing formations generally consisting of sands and gravels interbedded with clay layers fall within this group. The latter sites could depend on the competence of the nonwater-bearing formations as barriers and the ultimate use of the completed landfill.

Hydrology. In general, sites that are underlain by nonwater-bearing rocks, but have lateral continuity with ground water basins, should not be irrigated.

ates overlying confined ground water can be designated as Class II, provided that the bottom of the landfill is maintained at a reasonable distance above the bottom of the confining layer, and that hydraulic continuity between the site and the confined ground water body does not exist. In determining the competence of the confining layer, the following factors should be considered: rate of percolation through the confining layer; lateral movement of impeded percolate beyond the limits of the confining layer; and interconnections by active, inactive, and abandoned wells.

Topography. Here again, the topographic characteristics to be considered include surface drainage. Surface drainage from tributary areas must be diverted from the site. Whenever a watercourse passes through a site, a lined channel or pipeline must be provided with adequate capacity and, as necessary, protective works to ensure that normal flows and floodflows do not enter the landfill and cause erosion of deposited material and production of leachate. Direct precipitation on the site should be removed from the site to prevent percolation into the refuse and the subsequent formation of leachate. However, if site drainage penetrates any portion of the deposited refuse, it must be treated as leachate and confined to the site or collected and discharged to a sewer, storm drain, or stream channel in such manner that receiving waters are not adversely affected.

Class III

Landfill sites that afford little or no protection to receiving waters are designated as Class III. Class III sites have no geologic or hydrologic requirements. The only topographic requirements are to provide adequate channel capacity and protective works for any watercourse passing through the site to prevent erosion of deposited materials.

Corresponding materials suitable for safe disposal in Class III sites are Group 3 wastes.

Modification

Landfill sites can be modified -- usually by the construction of a physical barrier -- to protect the ground water. This protection may be great enough to upgrade what had been an unsuitable Class II site to a suitable site and even to a Class I. Types of physical barriers are clay layers, plastic membranes, and asphalt liners.

The type of barrier to be incorporated into the design and construction of a landfill on a particular site will depend on the nature of the impairment problem; that is, whether liquid or gaseous wastes pose the threat of impairment. In certain areas where there are low levels of rainfall and the subsequent application of water can be prevented, the problem of leachate impairment can be virtually eliminated by the use of simple preventive measures, and the problem would be that of gas impairment only. In other areas, where the level of rainfall is such that the formation of leachate cannot be prevented or the irrigation of the completed fill is anticipated, the dual problem exists. In all cases, however, prevention of gas movement is the overriding design factor, because barriers transmit gas more readily than liquids.

However, the barrier must be designed structurally to retain leachate. The leachate must then be removed (possibly by pumping) and discharged in such a manner that usable receiving waters are not adversely affected.

The development of various types of barriers to gas movement has been undertaken by Engineering-Science, Inc. under contract to the State Water Resources Control Board. Two types of barriers that have been tested are plastic membrane and asphalt liner.⁽²⁰⁾ A third type, which will be investigated in the near future, is the natural ventilation system.

The plastic membrane tested was a 10-mil polyethylene sheet. The membrane was sandwiched by layers of burlap, placed in a pit approximately 40 feet wide, 80 feet long, and 20 feet deep, and covered by a layer of soil for protection against puncture by refuse placement machinery. Gas sampling probes were placed on both sides of the membrane to measure CO₂ transfer. The pit was then filled with refuse. A typical installation of this type of barrier is shown in Figure 31.

Partial results of tests of gas transfer across the polyethylene barrier are plotted in Figure 32 as CO₂ concentra-

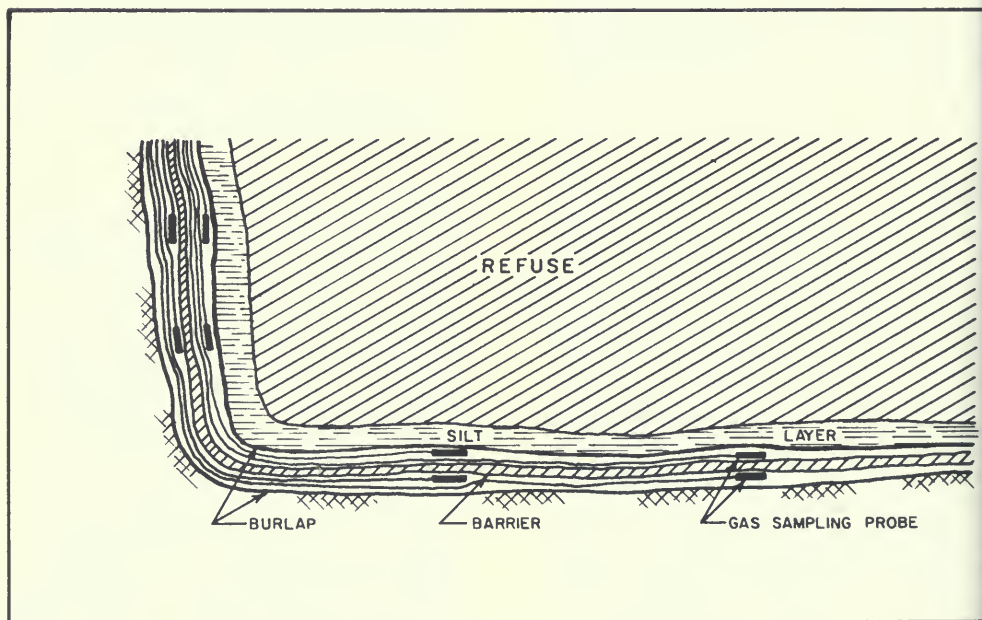


Figure 31 - TYPICAL INSTALLATION OF PHYSICAL BARRIER WITH GAS SAMPLING PROBES FOR TEST PURPOSES⁽¹⁸⁾

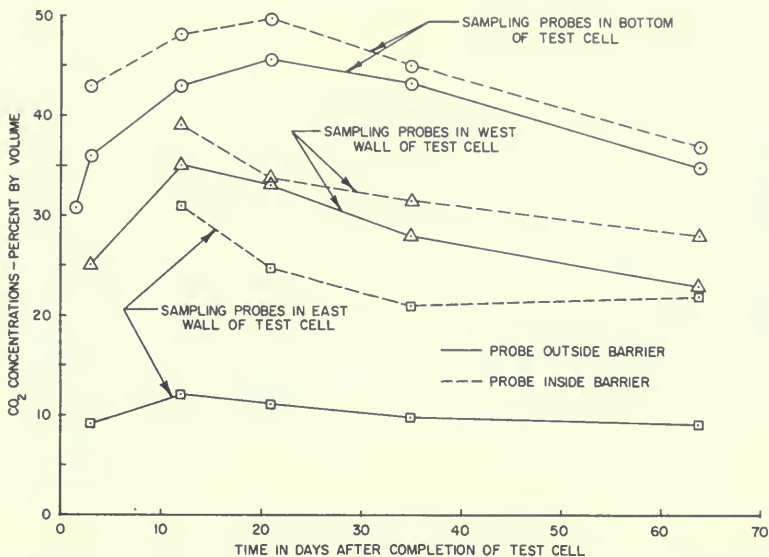


Figure 32— CARBON DIOXIDE CONCENTRATIONS INSIDE AND OUTSIDE THE POLYETHYLENE SHEET GAS BARRIER⁽¹⁸⁾

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1989

ons at selected sets of probes placed both sides of the membrane. The 50 to 60 percent reduction in CO₂ concentration across the barrier in the east wall of the test cell is approximately the reduction found in laboratory studies. The 10 to 20 percent reduction rates at the west wall and the bottom of the test cell indicated gas transfer across the membrane due to ruptures, which were revealed later, when the membrane was uncovered.

Similar tests were made on a test cell lined with asphalt sprayed on burlap. The liner was then protected with 6 to 8 inches of clay. Here again, the side walls received little protection because of the difficulty of placing clay on steep slopes.

Results of the gas transfer across the asphalt liner are plotted in Figure 33. CO₂ concentrations at the set of probes at the bottom of the test cell underwent a 75 percent reduction across the barrier, which is somewhat lower than the 90 percent reduction obtained in the laboratory studies. CO₂ reduction across the barrier at the probes located in the wall of the test cell was about 20 percent, again indicating passage of gas through ruptures and cracks in the asphalt.

It is estimated, by Engineering-Science, Inc., that the asphalt membrane and others of a similar type will increase the cost of landfill operation by 10 percent or less.

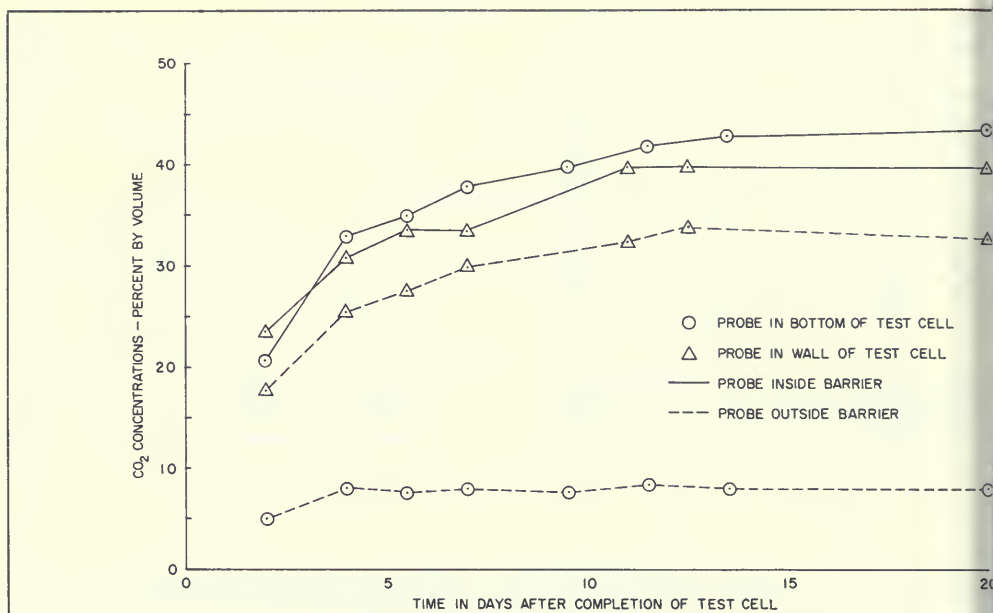


Figure 33 — CARBON DIOXIDE CONCENTRATIONS INSIDE AND OUTSIDE THE ASPHALT LINER GAS BARRIER⁽¹⁸⁾

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1965

Future studies will include the development of a natural ventilation system, as depicted in Figure 34. This system will consist of a clay layer to retard downward movement of gas, a coarse gravel layer to provide easy lateral movement of gas, and a coarse gravel wall or perforated pipe to provide easy movement of gas upward to the atmosphere. The bottom clay layer can be placed so that leachate can be retained and then removed by pumping.

An important consideration in the selection of a landfill site overlying an unconfined ground water body is the possibility that inundation of refuse will result in the formation of leachate, with subsequent impair-

ment of receiving ground waters. If the landfill is to be constructed with a barrier to the downward movement of refuse-derived gas and leachate, rising ground water could exert undue pressure, causing barrier failure by rupture or cracking. For this reason the lowest elevation of the landfill should be maintained a safe distance above anticipated high ground water level to provide a factor of safety for possible inaccuracies in the prediction of the anticipated high level or the barrier should be adequately designed to compensate for uplift forces.

If excessive leachate is expected from the landfill, a barrier, possi-

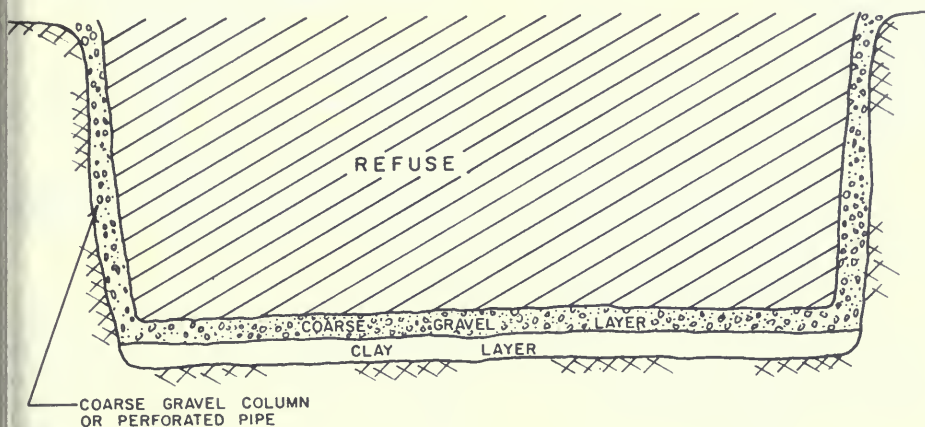


Figure 34. - NATURAL VENTILATION SYSTEM

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1969

If a cutoff wall, must be constructed to prevent lateral movement of the leachate and its subsequent impairment of receiving ground waters. Confined leachate must be discharged to a sewer, storm drain, or stream channel in such a manner that receiving waters are not adversely affected.

Construction and Operation Techniques

The problem of leachate formation can be lessened to a great degree and, in certain cases, can be virtually eliminated by proper landfill construction and operation procedures. To ensure that these proper procedures are followed, provision must be made for adequate administrative control.

Preventive procedures of primary importance include maintenance of a continuous earth cover on the refuse, sloping of the cover, control of drainage from adjacent areas and from the site, and control of water application for compaction and dust control.

Maintenance of a continuous, compacted cover, preferably of impermeable material, effectively reduces the amount of surface water that can infiltrate to the deposited refuse. Infiltration is also reduced by proper sloping of the refuse cover to enhance surface drainage to the extremities of the landfill. By reducing the amount of infiltration, the amount of leachate formed is automatically reduced. Other advantages of a continuous earth cover include reduction in fire

hazard and aid in the control of rats and other pests. An example of good construction technique is shown by the landfills of the County Sanitation Districts of Los Angeles County, in which, at the end of each day's operation, a continuous earth cover of 0.5 to 1 foot is placed, a 1- to 2-foot layer of earth is maintained between refuse layers, and a 3-foot minimum earth cover is placed on finished surfaces, including face slopes.

Drainage from the site and from adjacent areas is controlled by the following procedures: provision of adequate channel capacity and protective works through the site or upstream diversion of major flows from adjacent areas; collection of drainage from the site and minor drainage from adjacent areas in lined channels along the perimeter of the landfill; and provision of structures to convey the collected water to the downstream edge of the site.

When there is a need to control leachate formation and subsequent ground water impairment, water should not be used for compaction of refuse and cover material and only in very minor amounts for dust control.

Utilization of the Completed Landfill

Subsequent use and even nonuse of the land created by landfill disposal of refuse has a significant bearing on potential pollution of ground waters. In the use of completed landfills, just as in their construction and operation, adequate administrative controls are needed. Provision should be made to extend these controls to future use and ownership.

Uses of this land should be primarily restricted to crop planting, parks, golf courses, and parking areas, because of uneven settlement and the low bearing capacity of a fill containing refuse, which dictates flexible and nonconcentrated load usage. These uses, because of their water requirements, aid the

formation of leachate and gas, which increases the threat of ground water impairment. Nonuse of this land and the resulting exposure to rainfall can cause the same results.

For the above reasons, every completed landfill of the Class II type should be covered with a layer of clay asphalt, or some other impermeable material. Then, nonuse presents no problem, and the land can be used for the purposes listed above if a subdrain system and a topsoil layer are added, as shown in Figure 35.

The subdrain system must be extremely efficient in removing percolating water to ensure against possible leakage to the refuse below. Problems in the design and construction of this subdrain system arise because of uneven settlement of the landfill. These problems may be overcome, however, by using a coarse gravel layer to provide drainage. In this case, the impermeable layer is designed as a sump and the gravel layer as a collector. Provision must then be made for disposing of the collected water out of the sump, with discharge to some suitable waterway.

The topsoil layer is then added to support plant growth. This layer of topsoil must be of sufficient thickness to prevent root growth from reaching the impermeable layer, which could cause failure of the impermeable layer, allowing passage of water to the refuse below.

Economic Considerations

Economic considerations, although basic to all sites, will vary considerably in magnitude from site to site. Each site will have a particular set of physical characteristics (geology, hydrology, and relationship to receiving waters) that will govern the feasibility of its use as a landfill. Therefore, each landfill site should be analyzed as a separate entity, treating each site as a system.

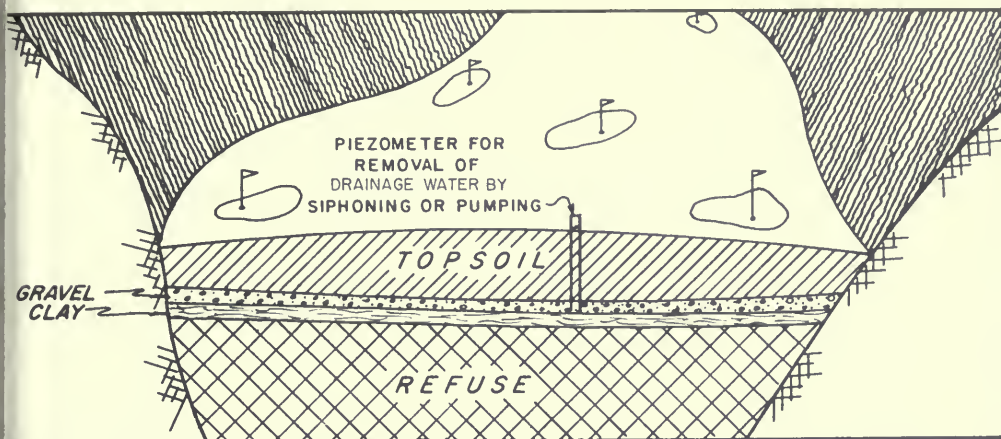


Figure 35.-PERSPECTIVE OF COMPLETED LANDFILL USING SUBGRADE DRAINAGE

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The primary economic factors that will determine the feasibility of utilizing a particular site are the land, haul distance, construction and operation costs, the cost of providing protective works for receiving ground and surface waters, and the value of the land created by the completed landfill. The first three items are easily determined. The cost of protective works should be compared with the decrease in economic value of the receiving water, determined by its established

beneficial uses versus the cost of an alternative supply. The probable decrease in value or water quality benefits foregone will dictate the degree of protection required. The justifiable costs of barriers and other protective works required can then be determined. The value of the created land is considered a benefit to be gained from the landfill and will depend on its geographical location and on its area and ultimate usage.



ATTACHMENT 1

BIBLIOGRAPHY



ATTACHMENT 1

BIBLIOGRAPHY

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ATTACHMENT 2

DEFINITIONS

ATTACHMENT 2

DEFINITIONS

The following words and terms are defined as used in this report.

Acre-foot. The volume of water required to cover one acre one foot in depth (43,560 cubic feet, or 325,851 gallons).

Alluvium. A general term for stream-deposited, sedimentary materials, usually of Recent geologic age.

Aquifer. A geologic formation, or zone, sufficiently permeable to yield an appreciable supply of water to wells or springs.

Biochemical Oxygen Demand (BOD). The amount of oxygen required by bacteria while stabilizing decomposable organic matter in the presence of air.

Chemical Oxygen Demand (COD). The amount of oxygen required to oxidize all organic compounds (biologically stable and unstable) to carbon dioxide and water by the action of strong oxidizing agents under acid conditions. As a result, COD values are greater than BOD values.

Confined Ground Water. A body of ground water that is immediately overlain by material sufficiently impervious to sever free hydraulic connection with overlying water, and that moves under gradient or pressure caused by the difference in head between the intake, or fore-bay area, and the discharge area of the confined water body.

Contamination. Defined in Section 13005 of the California Water Code: "...an impairment of the quality of the waters of the State by sewage or industrial waste to a degree which creates an actual hazard to public health through poisoning or through the spread of disease...." Jurisdiction over matters regarding contamination rests with the California Department of Public Health and local health officers.

Degradation. Impairment of the quality of water due to causes other than disposal of sewage and industrial waste.

Deterioration. Impairment of water quality.

Electrical Conductance. The reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a temperature of 25 degrees centigrade.

Evapotranspiration. Loss of water from the soil both by evaporation and by transpiration from the plants growing thereon. In this report, evapotranspiration is synonymous with consumptive use.

Fault. A fracture or fracture zone along which the two sides have been displaced relative to each other parallel to the fracture. The displacement may be a few inches or many miles.

Field Capacity. Moisture content of soil after drainage by gravity is complete.

Fresh Water. Water containing less than 1,500 parts per million total dissolved solids.

Ground Water. Subsurface water occurring in the zone of saturation and moving under control of the water table slope or piezometric gradient.

Ground Water Basin. An area underlain by one or more permeable formations capable of furnishing a substantial water supply.

Ground Water Storage. That stage of the hydrologic cycle during which water occurs as ground water in the zone of saturation, including that part of such stage when water is passing through the zone of aeration and entering or leaving storage.

Hydraulic Gradient. Under unconfined ground water conditions, the slope of the profile of the water table. Under confined ground water conditions, the line joining the elevations to which the water would rise in wells if they were perforated in the aquifer.

Hydrology. The applied science concerned with the waters of the earth, their occurrence, distribution, use and circulation through the unending cycle of precipitation; consequent runoff, infiltration, storage, use, and disposal; eventual evaporation; and reprecipitation. It is concerned with the physical and chemical reaction of water with the rest of the earth and its relation to the life of the earth.

Hydrology, Ground Water. The branch of hydrology that treats subsurface water -- its occurrence, movement, and storage, its replenishment and depletion -- also, of the properties of unconsolidated materials and rocks that control the occurrence, movement, and storage of subsurface water, and the method of investigation and utilization of subsurface water.

Impairment. A change in quality of water which makes it less suitable for beneficial use.

Industrial Waste. Defined in Section 13005 of the California Water Code: "...any and all liquid or solid waste substance, not sewage, from any producing, manufacturing or processing operation of whatever nature...."

Infiltration. Water passing from the surface into the soil.

Leachate. Water solution consisting of dissolved minerals and gases derived from refuse decomposition through respiration reaction and from soluble material in the refuse.

Oxidation. Chemical combination with oxygen.

pH. The logarithm, to the base 10, of the reciprocal of the hydrogen ion concentration, or more precisely, of the hydrogen ion activity, in moles per liter. Distilled water (at 25 degrees centigrade) has a pH of 7; values less than 7 indicate acidic solutions, while values greater than 7 indicate basic (alkaline) solutions.

Parts Per Million (ppm). One weight of solute per million weights of solution at a temperature of 20 degrees centigrade. For practical purposes, ppm is the same as milligrams per liter (mg/l).

Perched Ground Water. Ground water separated from an underlying body of ground water by unsaturated rock. Perched water belongs to a different zone of saturation from that occupied by the underlying ground water, and its water table is a perched water table.

Percolation. The movement, or flow, of water through the interstices, or pores, of a soil or other porous media.

Permeability. The permeability (or perviousness) of rock is its capacity for transmitting a fluid. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the interconnections.

Pollution. Defined in Section 13005 of the California Water Code: "...an impairment of the quality of the waters of the State by sewage or industrial waste to a degree which does not create an actual hazard to the public health but which does adversely and unreasonably affect such waters for domestic, industrial, agricultural, navigational, recreational or other beneficial use, or which does adversely and unreasonably affect the ocean waters and bays of the State devoted to public recreation." Regional Water Quality Control Boards are responsible for prevention and abatement of pollution.

Refuse. Solid waste material resulting from normal community activity.

Sanitary Landfill. A method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical volume and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary.

Specific Yield. The ratio of the volume of water a saturated sediment will yield by gravity drainage to the total volume of the sediment and water prior to draining, customarily expressed in percent.

Syncline. A fold in rocks in which the strata dip inward from both sides toward the axis.

Total Dissolved Solids (TDS). The dry residue from the dissolved matter in an aliquot of a water sample remaining after evaporation of the sample at a definite temperature.

Transmissibility, Coefficient of. The rate of flow of water, expressed in gallons per day, at the prevailing water temperature through each verticle strip, one foot wide, having a height equal to the thickness of the aquifer, and under a unit hydraulic gradient.

Unconfined Ground Water. Ground water that is not immediately overlain by impervious materials and that moves under control of the water table slope.

Waste Water. Water that has been put to some use or uses and has been disposed of, commonly to a sewer or wasteway. It may be liquid industrial waste or sewage or both.

Water Table. The surface of ground water at atmospheric pressure in an unconfined aquifer. This is revealed by the levels at which water stands in wells penetrating the unconfined aquifer.

Well. A shaft or hole sunk into the earth to obtain oil, gas, water, etc., or for injecting fluids into the earth.

ATTACHMENT 3

IDENTIFICATION SYSTEM AND
CRITERIA USED IN REPORT

ATTACHMENT 3

IDENTIFICATION SYSTEM AND CRITERIA USED IN REPORT

This appendix contains explanations of the sampling point identification system and water quality criteria used in preparation of this study and report.

Sampling Point Identification System

Wells from which samples of water or measurements to depth to ground water have been obtained are assigned state well numbers. For these, wells are referenced by use of the United States Public Land Survey System. The well number consists of the township, range, and section numbers, a letter to indicate the 40-acre lot in which the well is located, a number to identify the particular well in the 40-acre lot, and a terminal letter to indicate the base and meridian in question, i.e., H for Humboldt Base and Meridian, M for Mount Diablo Base and Meridian, or S for San Bernardino Base and Meridian.

Sections are subdivided into 40-acre lots as shown below. For example, well 1S/11W-13N3 S denotes the third well to be assigned a number in Lot N of Section 13 of Township 1 South, Range 11 West, San Bernardino Base and Meridian.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Section lines have not generally been surveyed into areas included in the Spanish and Mexican Land grants. So that the state well number system may be used in these areas, section lines have been projected across the ranchos on the standard United States Geological Survey quadrangle sheets. The projections of section lines used for well numbering in the Southern District are delineated on quadrangle sheets in the Los Angeles office of the Department of Water Resources. It is suggested that interested agencies and individuals desiring to project section lines for well numbering trace the projections from the Department's maps to avoid conflicts and confusion in assigning well numbers.

Water Quality Criteria

Water, whether consumed directly by man or used to produce the comforts

and necessities of his life, to irrigate the plants he uses for food or the plants he enjoys visually and as shade, or to furnish sustenance for the animals that provide him meat, must be of a quality fit to use. The quality demanded for any particular use, of course, depends on the exigencies peculiar to that use.

Many sets of guidelines by which the suitability of water may be judged have been suggested by authorities to codify the requirements for water quality for beneficial use. Included in these attempts at classification are several terms, some of which may appear strange or confusing to the reader; among them are standards, criteria, and objectives. Unfortunately, no uniform terminology has been adopted by all or even most of those concerned with the quality of the water resource. This section defines the terms as used in this report.

Definition of Terms

Before any discussion of water quality classification can be presented, it is necessary to explain several terms. These are:

Standards. Standards are those values established by some regulatory agency as obligatory limits on water quality. Perhaps the best known of these are the United States Public Health Service Drinking Water Standards. Equally important to any discussion of water quality criteria in California are those standards established by the California Department of Public Health. The two sets of standards differ only slightly.

Criteria. As opposed to standards, criteria are guidelines for judging water for a particular use. They are more general than standards and are by no means obligatory. Criteria must be cited with reference to the use for which a particular water source is intended as they can vary from place to place and with a given situation. The discussion here is only intended as a brief summary; for a more definitive work, the reader is referred to the excellent treatise by Dr. J. E. McKee and H. W. Wolfe, entitled, "Water Quality Criteria", to mention only one of many books on the subject.

Objectives. Objectives refer to the level of water quality desired. They are used most often with respect to ground water in one basin or to surface water in a given stream, lake, bay, or area of the ocean. Generally, objectives are goals for water quality that are thought to be reasonable to maintain in a natural body of water, particularly one which receives some discharge of manmade waste. It might be noted here that use of the term objectives usually implies that the objectives have been established by some regulatory agency. It should also be stressed that, for effective water quality control, objectives should only be established after due deliberation and study, and they should be reexamined periodically. Objectives are dynamic and should be modified according to changes in the environment.

Specific Uses

With the general terminology defined, the specific requirements for various uses can now be examined.

Domestic Use. Water used for drinking and culinary purposes should be clear, colorless, odorless, pleasant tasting, and free from toxic salts. It should not contain excessive amounts of dissolved minerals and must be free from pathogenic organisms. In addition to these physical and bacteriological requirements, certain qualifications are generally placed on chemical quality, either as requirements by a regulatory agency or for comparative grading of different waters.

The 1962 Drinking Water Standards of the United States Public Health Service are applicable only to drinking water and water supply systems used by interstate carriers and others subject to Federal quarantine regulations. However, they have been adopted by the entire water works profession as minimum standards for control and are widely quoted.

The standards themselves, as promulgated, include discussions of bacteriological, physical, radiological, and chemical aspects. Only the chemical aspects will be discussed here. Table 32 presents the standards; the recommended values are those which should not be exceeded in a water supply if other more suitable supplies are or can be made available. The mandatory values are those which, if exceeded, constitute grounds for rejection of the supply.

The standards for fluoride are related to the annual average of maximum daily air temperatures (based on a minimum five-year record) and are presented in Table 33. The average concentration should not exceed the appropriate upper limit in the table. The presence of fluoride in average concentrations greater than twice the optimum values in Table 33 constitutes grounds for rejection of the supply. The standards further state that where fluoridation is practiced, the average fluoride concentration shall be kept within the upper and lower control limits in Table 33.

In California, the State Board of Public Health issues water supply permits in accordance with its "Interim Policy on Mineral Quality of Drinking Water", as adopted September 4, 1959, and in accordance with "Policy Statement and Resolutions by the State Board of Public Health with Respect to Fluoride Ion Concentrations in Public Water Supplies", as approved August 22, 1958. The interim policy on mineral quality is presented as follows:

1. Water supply permits may be issued for drinking and culinary purposes only when the Public Health Service Drinking Water Standards of 1946^{1/} and the State Board of Public Health policy on fluorides are fully met.

^{1/} Author's Note: It is assumed, in the absence of any later standards that the 1962 edition of the Drinking Water Standards now applies.

TABLE 32

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS, 1962

Substance	: Recommended : limits : concentrations : in mg/l	: Mandatory : limits : concentrations : in mg/l
Alkyl benzene sulfonate (ABS)	0.5	--
Arsenic (As)	0.01	0.05
Barium (Ba)	--	1.0
Cadmium (Cd)	--	0.01
Carbon chloroform extract (CCE)	0.2	--
Chloride (Cl)	250	--
Chromium (hexavalent) (Cr ⁶)	--	0.05
Copper (Cu)	1.0	--
Cyanide (CN)	0.01	0.2
Fluoride (F)	**	**
Iron (Fe)	0.3	--
Lead (Pb)	--	0.05
Manganese (Mn)	0.05	--
Nitrate (NO ₃)*	45	--
Phenols	0.001	--
Selenium (Se)	--	0.01
Silver (Ag)	--	0.05
Sulfate (SO ₄)	250	--
Total dissolved solids (TDS)	500	--
Zinc (Zn)	5	--

*In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

**See Table 33.

TABLE 33

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS, 1962 -- FLUORIDE

Annual average of maximum daily air temperatures, in degrees Fahrenheit	: Recommended control limits -- : fluoroide concentrations, in mg/l	: Lower	: Optimum	: Upper
50.0 - 53.7		0.9	1.2	1.7
53.8 - 58.3		0.8	1.1	1.5
58.4 - 63.8		0.8	1.0	1.3
63.9 - 70.6		0.7	0.9	1.2
70.7 - 79.2		0.7	0.8	1.0
79.3 - 90.5		0.6	0.7	0.8

2. In view of the wide variation in opinion in this field, the uncertainty as to the long-time health effects, the uncertainty of public attitude concerning various mineral levels, and the obvious need for further study, temporary permits may be issued for drinking water supplies failing to meet the Drinking Water Standards if the mineral constituents do not exceed those listed under the heading 'Temporary Permit' in the following table:*

UPPER LIMITS OF TOTAL SOLIDS AND SELECTED MINERALS IN
DRINKING WATER AS DELIVERED TO THE CONSUMER

	Permit	Temporary Permit (In milligrams per liter)
Total Solids	500 (1,000)**	1,500
Sulfates	250 (500)**	600
Chlorides	250 (500)**	600
Magnesium	125 (125)	150

*This interim policy relates to potable water and is not intended to apply to a secondary mineralized water supply intended for domestic uses other than drinking and culinary purposes.

**Numbers in parentheses are maximum permissible, to be used only where no other more suitable waters are available in sufficient quantity for use in the system.

3. Exception: No temporary permit for drinking water supplies in which the mineral constituents exceed those listed under the heading 'Temporary Permit' as set forth in #2 above may be issued unless the Board determines after public hearing:

- (a) The water to be supplied will not endanger the lives or health of human beings; and
- (b) No other solution to meet the local situation is practicable and feasible; and
- (c) The applicant is making diligent effort to develop, and has reasonable prospect of developing a supply of water which will warrant a regular permit within an acceptable period of time.

The burden of presenting evidence to fulfill the requirements as set forth in (a), (b), and (c) above is upon the applicant.

With respect to fluoride concentration, the State Board of Public Health has defined the maximum safe amounts of fluoride ion in relation to mean annual temperature as shown in Table 34.

TABLE 34

CALIFORNIA STATE BOARD OF PUBLIC HEALTH,
MAXIMUM FLUORIDE ION CONCENTRATIONS

Mean annual temperature, in degrees Fahrenheit*	:	Mean monthly fluoride concentration, in milligrams per liter
50		1.5
60		1.0
70 - above		0.7

*For temperature values between those shown in the table, the fluoride ion concentrations may be obtained by interpolation.

The State Board of Public Health's policy on fluoride ion further states that:

1. The concentration of the fluoride ion in public water systems, whether added or naturally occurring, should not exceed the fluoride ion concentrations stated in the above table.
2. In the development of new public water systems used for drinking and culinary purposes, the above fluoride ion concentrations shall not be exceeded.
3. In existing public water systems used for drinking and culinary purposes in which the above fluoride ion concentrations are exceeded, the fluoride ion concentration shall be reduced to a safe level by the use of methods acceptable to the State Department of Public Health. Exception: In cases where the Department determines after investigation that it is not practicable and feasible to reduce the fluoride ion concentration in the entire supply to a safe level, special methods, acceptable to the State Department of Public Health, shall be provided by the applicant to furnish water of suitable fluoride ion concentration to all children 10 years of age or under.

Hardness of waters varies considerably from place to place. However, total hardness is a significant factor in the determination of the suitability of water for domestic and industrial use. A general classification, in terms of the degree of hardness as CaCO_3 , is presented here. Waters for domestic use are commonly classified as follows:

0 - 75 mg/l	soft
75 - 150 mg/l	moderately hard
150 - 300 mg/l	hard
300 mg/l	very hard

Levels of hardness tolerable or desirable in water used for various industrial purposes are summarized in the following tabulation:

Industry and process	: :	Limiting or recommended values in mg/l
Boiler feed water		2 - 80
Brewing		200 - 300
Food processing (general)		10 - 250
Laundering		0 - 50
Pulp and paper making		100 - 200
Rayon cloth manufacturing		55
Steel manufacturing		50
Synthetic rubber manufacturing		50
Textile manufacturing		0 - 50

Agricultural Use. The major criteria for judging the suitability of water for irrigation are chloride concentration, specific electrical conductance (presented as $EC \times 10^6$ at $25^\circ C$), boron concentration, and percent sodium.

Chlorides are present in nearly all waters. They are not necessary to plant growth, and in high concentrations cause subnormal growing rates and burning of leaves.

Electrical conductance indicates the total dissolved solids and furnishes an approximate indication of the overall mineral quality of the water. For most waters, the total dissolved solids, measured in parts per million (ppm), may be approximated by multiplying the electrical conductance by 0.7. As the amount of dissolved salts in irrigation water increases, the crop yields are reduced until, at high concentrations (the value depending on the plant, type of soil, climatological conditions, and amount of water applied), plants cannot survive.

Boron is never found in the free state, but occurs as borates or boric acid. This element is essential in minor amounts for the growth of many but not all plants. It is, however, extremely toxic to most plants in higher concentrations. Limits of tolerance for most irrigated crops vary from 0.5 to 2.0 ppm. Citrus crops, particularly lemons, are sensitive to boron in concentrations exceeding 0.5 ppm.

The percent sodium, as reported in analyses, is 100 times the proportion of the sodium cation to the sum of all cations, all expressed in equivalents per million (epm). Water containing a high percent sodium has an adverse effect upon the physical structure of soils that contain clay by dispersing the soil colloids. This, in turn, retards the movement of water and the leaching of salts, and makes the soils difficult to work. The effect of potassium in water is similar to that of sodium.

Because of the diverse climatological conditions, crops, soils, and irrigation practices in California, criteria that may be set up to es-

establish the suitability of water for irrigation must necessarily be of a general nature, and judgment must be used in applying these criteria to individual cases.

Based on results of studies by Dr. L. D. Doneen, Professor of Water Science and Engineering at the University of California at Davis, three general classes of irrigation water have been established.

- Class 1 Excellent to Good. Regarded as safe and suitable for most plants under any condition of soil or climate.
- Class 2 Good to Injurious. Regarded as possibly harmful for certain crops under certain conditions of soil or climate, particularly in the higher range of this class.
- Class 3 Injurious to Unsatisfactory. Regarded as probably harmful to most crops and unsatisfactory for all but the most tolerant.

Limiting values for concentrations of chloride, boron, specific electrical conductance, and percent sodium for these three classes of irrigation water have been established and are shown in Table 35.

Tables 36 and 37 were extracted from U. S. Department of Agriculture Technical Bulletin 962, "The Quality of Water for Irrigation Use, 1948", by L. V. Wilcox, and are presented to show the relative tolerance of crop plants to irrigation waters containing boron. Table 38 shows the relative tolerance of crop plants to salt.

Industrial Water Use. Criteria of quality of water for industrial purposes are exceedingly difficult to ascertain. Industrial usage of water is so varied that a single set of criteria for chemical, physical, and bacterial requirements would be meaningless. The attempt made in Table 39 to assign approximate water quality requirements to general types of industries is, therefore, a very general one, and the quality limits should be considered flexible. Even criteria obtained for the industries mentioned are not conclusive for all constituents. Water used for industrial purposes must, therefore, be considered as a raw material to be treated, if necessary, by the user to fit individual needs.

TABLE 35

CRITERIA FOR IRRIGATION WATERS

Factors	: Class 1 - : Excellent : to good	: Class 2 - : Good to : injurious	: Class 3 - : Injurious to : unsatisfactory
Specific electrical conductance, $EC \times 10^6$ at 25° C	Less than 1,000	1,000 - 3,000	More than 3,000
Boron, mg/l	Less than 0.5	0.5 - 2.0	More than 2.0
Chloride, mg/l	Less than 175	175 - 350	More than 350
Percent sodium	Less than 60	60 - 75	More than 75

TABLE 36

PERMISSIBLE LIMITS OF BORON FOR
SEVERAL CLASSES OF IRRIGATION WATER

In milligrams per liter

Classes of Water	Crop groups		
	Sensitive	Semitolerant	Tolerant
Excellent	less than 0.33	less than 0.67	less than 1.00
Good	0.33 to 0.67	0.67 to 1.33	1.00 to 2.00
Permissible	0.67 to 1.00	1.33 to 2.00	2.00 to 3.00
Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
Unsuitable	more than 1.25	more than 2.50	more than 3.75

TABLE 37

RELATIVE TOLERANCE OF CROP PLANTS TO BORON*

Sensitive to boron	Semitolerant to boron	Tolerant to boron
Lemon	Lima bean	Carrot
Grapefruit	Sweet potato	Lettuce
Avocado	Bell pepper	Cabbage
Orange	Tomato	Turnip
Thornless blackberry	Pumpkin	Onion
Apricot	Zinnia	Broadbean
Peach	Oat	Gladiolus
Cherry	Milo	Alfalfa
Persimmon	Corn	Garden beet
Kadota fig	Wheat	Mangel
Grape (Sultanina and Malaga)	Barley	Sugar beet
Apple	Olive	Palm (Phoenix carariensis)
Pear	Ragged robin rose	Date palm (P. dactylifera)
Plum	Field pea	Asparagus
American elm	Radish	
Navy bean	Sweet pea	Tamarix, or athel (Tamarix aphylla and T. gallica)
Jerusalem artichoke	Pima cotton	
Persian (English walnut)	Acala cotton	
Black walnut	Potato	
Pecan	Sunflower (native)	

*In each group the plants first named are considered as being more sensitive and the last named more tolerant

TABLE 38

RELATIVE TOLERANCE OF CROP PLANTS TO SALT*

Low salt tolerance	Medium salt tolerance	High salt tolerance
Pear	Pomegranate	Date palm
Apple	Fig	Salt grass
Orange	Olive	Bermuda grass
Grapefruit	Sweet corn	Rescue grass
Prune	Potato (White Rose)	Western wheatgrass
Plum	Carrot	Barley
Almond	Onion	Sugar beet
Apricot	Sudan grass	Rape
Peach	Alfalfa (California common)	Cotton
Strawberry	Rye	
Lemon	Wheat	
Avocado	Oats	
Field bean	Orchardgrass	
Radish	Rice	
Celery	Meadow fescue	
Meadow foxtail	Sorghum (grain)	
Red clover	Corn (field)	
	Flax	
	Sunflower	
	Castorbean	

*Based on Agriculture Handbook No. 60, U.S. Department of Agriculture.
February 1954.

TABLE 39

LIMITS OF MINERAL CONCENTRATIONS, PHYSICAL PROPERTIES,
AND SANITARY QUALITY OF WATER FOR VARIOUS INDUSTRIAL USES

Allowable limits in parts per million except as noted

Constituent or property	Boiler feed water ^a boiler pressure in pounds per square inch				Concrete mixing ^a	Cooling water ^{a, f}	Steel manufac- turing ^a	Tanning operations ^a	Textile manufac- turing ^a	Production of paper ^a	
	0-150	150-250	250-400	over 400						Ground- wood ^g	Soda and sulfate pulp ^h
Total Solids	3,000- 500 ^b	2,500- 500 ^b	1,500- 100 ^b	50 ^b	--	--	--	--	--	--	--
pH value	8.0 minimum	8.4 minimum	9.0 minimum	9.6 minimum	high values desired	7 to 9 ^f	6.8 to 7.0	6.0 to 8.0	--	--	--
Chlorides (Cl)	--	--	--	--	--	--	175	--	100	75	75
Iron (Fe)	--	--	--	--	--	0.5 ^k	--	0.1 to 2.0	0.1 to 1.0	0.3	0.1
Manganese (Mn)	--	--	--	--	--	0.5 ^k	--	0.1 to 0.2	0.05 to 1.0	0.1	0.05
Iron and Manganese (Fe + Mn)	--	--	--	--	--	0.5 ^k	--	0.2	0.2 to 1.0	--	--
Suspended matter	--	--	--	--	--	--	25	--	--	--	--
Temperature, °F.	20	10	5	1	--	50 ^k	75	20	0.3 to 25	--	--
Turbidity	80	40	5	2	--	--	--	10 to 100	0 to 70	30 ^j	5 ^j
Color	1.4 ^c	0.14	0.05 ^c	0.02 ^c	--	--	--	--	--	--	--
Dissolved oxygen	5 ^d	3 ^d	0 ^d	0 ^d	--	--	--	--	--	--	--
Hydrogen sulfide (H ₂ S)	80	40	10	2	100 minimum	50 ^k	50	50 to 513	0 to 50	200	100
Total hardness (as CaCO ₃)	1:1	2:1	3:1	0.01	--	--	--	--	--	--	--
Sulfate-carbonate ratio (ASCR)	5	0.5	0.05	1	--	--	--	--	--	--	--
(Mg SO ₄ : Na ₂ CO ₃)	40	20	5	1	--	--	--	--	--	--	--
Aluminum oxide (Al ₂ O ₃)	50 ^e	30 ^e	5 ^e	0 ^e	--	--	--	--	--	--	--
Bicarbonate (HCO ₃)	200	100	40	20	--	--	--	--	--	--	--
Carbonate (CO ₃)	50	40	30	15	--	--	--	--	--	--	--
Hydroxide (OH)	15	10	4	3	--	--	--	--	8	--	--
Oxygen consumed	--	--	--	--	--	2,500 ^f	--	--	--	500	250
Total dissolved solids	--	--	--	--	--	--	--	--	--	--	--
Free carbon dioxide (CO ₂)	--	--	--	--	25	--	--	--	--	10	10
Sulfite (SO ₃)	--	--	--	--	25	--	--	--	--	--	--
5 day BOD	--	--	--	--	--	--	25	--	--	--	--
Corrosion potential	--	--	--	--	--	--	Low as possible	--	--	--	--
Alkalinity (as CaCO ₃)	--	--	--	--	--	--	--	128 to 135	--	150	75
Heavy metals	--	--	--	--	--	--	--	--	None	--	--
Calcium (Ca)	--	--	--	--	--	--	--	--	10	--	--
Magnesium (Mg)	--	--	--	--	--	--	--	--	5	--	--
Sulfate (SO ₄)	--	--	--	--	--	--	--	--	100	--	--
Turbidity (as SiO ₂)	--	--	--	--	--	--	--	--	--	50 ^k	25 ^k
Silica (soluble as SiO ₂)	--	--	--	--	--	--	--	--	--	50	20
Calcium hardness (as CaCO ₃)	--	--	--	--	--	--	--	--	--	--	50
Magnesium hardness (as CaCO ₃)	--	--	--	--	--	--	--	--	--	--	50
Bicarbonate (as CaCO ₃)	--	--	--	--	--	--	--	--	200	--	--

a. California State Water Quality Control Board, "Water Quality Criteria", Publication No. 3-A, 1963.

b. Depends on design of boiler.

c. Limits applicable only to feed water entering boiler, not to original supply.

d. Except where odor in live steam would be objectionable.

e. Water considered good enough to drink is considered safe for concrete unless otherwise noted.

f. California State Water Pollution Control Board, "A Survey of Direct Utilization of Waste Waters", Publication No. 12, 1955.

g. Groundwood papers are coarse papers composed primarily of groundwood fibers such as are used for newspapers, telephone

directories, cheaper grades of catalogues, and pulp magazines.

h. Pulp produced by chemical cooking processes known as the soda process and the sulfate or kraft process are also called alkaline pulps.

i. Color in platinum units.

j. Materials causing turbidity shall not be gritty.

ATTACHMENT 4

MINERAL ANALYSES OF
TYPICAL GROUND WATERS

TABLE 40
MINERAL ANALYSES OF TYPICAL GROUND WATERS - AZUSA AREA

State, well number	Temp when sampled m°F	pH	Specific conductance (micro-mhos at 25°C)	Mineral constituents in parts per million														Total ppm as CaCl ₂
				Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO ₃	Bicarbonate HCO ₃	Sulfate SO ₄	Chloride Cl	Nitrate NO ₃	Fluoride F	Boron B	Silica SiO ₂	TDS		
Date sampled																		
1/104-32J2																		
1-13-63	66	7.8	390	59	13	12	3.5	0	220	38	9	9	0.2	0.05	10	270	203	
2-23-63	--	7.8	410	52	15	12	3.3	0	201	29	7	9	0.2	0.05	11	234	192	
1-17-64	--	7.7	420	60	11	14	3.0	0	204	28	14	7	0.2	0.10	--	250	194	
2-9-64	--	7.9	415	56	12	10	3.0	0	201	35	8	7	0.4	0.05	--	210	169	
2-9-65	64	8.2	407	53	15	11	3.0	0	203	35	F	4	0.3	0.06	--	237	193	
1/104-34L1																		
1-7-63	64	7.4	482	66	13	12	3.0	0	212	23	12	40	0.4	0.04	21	290	216	
1-24-63	70	7.6	450	54	15	13	3.4	0	217	32	6	6	0.2	0.08	13	270	197	
1-13-64	--	7.4	500	78	7	15	3.0	0	215	36	13	40	0.4	0.14	--	334	222	
2-7-64	--	7.9	496	70	13	12	4.0	0	218	28	13	38	0.4	0.04	--	323	225	
2-2-65	67	8.0	486	64	14	13	3.0	0	204	28	17	40	0.4	0.02	--	260	217	
1/104-34L1																		
1-24-63	--	7.5	700	46	45	28	2.0	0	281	34	20	86	0.2	0.05	22	483	300	
1-13-64	--	7.7	670	78	27	32	2.0	0	295	32	22	78	0.2	0.07	--	434	305	
2-9-64	--	7.9	694	91	20	25	2.0	0	290	41	20	66	0.6	0.03	30	458	300	
2-2-65	69	8.1	694	89	22	26	2.0	0	281	43	21	75	0.5	0.03	--	440	313	
1/104-35J2																		
1-24-63	71	7.6	620	62	26	24	3.6	0	265	27	20	46	0.2	0.20	20	392	260	
8-12-64	--	7.7	625	89	13	27	3.0	0	274	39	24	49	0.2	0.29	--	410	280	
8-31-65	--	8.1	636	86	17	24	3.0	0	273	39	26	44	0.3	0.19	--	390	260	
1/104-35M1																		
3-22-62	--	7.6	471	65	13	15	4.0	0	229	29	20	14	0.2	0.13	15	360	220	
2-25-63	--	7.7	432	65	7	14	4.0	0	222	31	d	3	0.4	0.06	15	250	194	
7-23-63	--	7.7	425	50	18	12	4.0	0	209	35	7	6	0.2	0.05	11	262	194	
2-14-64	--	7.9	510	69	12	17	3.4	0	235	26	12	18	0.2	0.15	17	300	224	
7-7-64	--	7.6	605	79	17	22	3.0	0	270	37	19	41	0.2	0.10	--	374	270	
8-17-64	--	7.8	670	72	23	17	3.0	0	272	50	16	40	0.2	0.15	--	380	270	
2-9-64	--	7.8	438	61	12	12	3.0	0	226	33	7	6	0.3	0.06	--	261	200	
1-20-65	--	7.8	465	57	15	32	3.0	0	213	53	25	2	0.4	0.17	--	290	202	
3-30-65	67	7.6	500	60	26	18	3.0	0	312	23	17	1	0.4	0.15	--	380	255	
8-30-65	71	8.0	440	54	14	16	3.0	0	187	28	21	21	0.3	0.09	--	274	190	
1/104-38K3																		
3-7-58	68	7.9	637	78	22	25	3.2	0	266	34	21	17	0.5	0.15	30	420	287	
1-13-63	66	7.6	640	87	21	25	3.2	0	277	52	21	76	0.2	0.07	22	430	301	
7-24-63	70	7.5	680	80	22	28	3.1	0	263	35	20	76	0.2	0.00	21	430	289	
3-12-64	--	7.5	600	67	30	29	4.0	0	256	30	19	--	0.2	0.05	--	414	291	
2-7-64	--	8.0	677	84	21	23	3.0	0	256	46	21	--	0.6	0.04	--	450	295	
2-1-65	68	8.3	688	83	22	25	3.0	10	226	45	26	94	0.4	0.04	--	423	290	
1/104-44R2																		
7-16-61	--	7.4	626	85	25	21	3.1	0	262	41	53	51	0.3	0.03	21	371	315	
3-14-63	--	7.8	600	76	22	22	3.4	0	268	49	23	44	0.2	0.02	21	412	280	
7-23-63	70	7.8	660	56	34	22	3.4	0	266	38	21	44	0.2	0.03	21	418	278	
8-18-64	--	7.5	590	59	30	26	3.0	0	268	38	22	55	0.2	0.05	--	386	275	
2-8-64	--	7.7	629	85	16	21	3.0	0	264	41	20	53	0.4	0.03	--	417	278	
1/104-68M1																		
3-14-63	60	7.7	330	50	8	17	3.0	0	189	32	7	8	0.2	0.05	14	254	159	
7-26-63	67	7.7	345	52	7	9	3.0	0	180	16	5	7	0.2	0.05	11	188	160	
8-18-64	--	7.4	370	66	4	11	3.0	0	187	22	13	9	0.2	0.07	--	234	180	
2-11-64	--	7.9	393	56	11	8	3.0	0	187	30	10	9	0.4	0.05	--	200	185	
2-1-65	64	8.2	430	56	14	8	3.0	0	194	30	17	9	0.3	0.03	--	209	198	
1/104-74G6																		
7-26-63	67	7.7	750	106	17	16	4.0	0	214	42	101	11	0.2	0.05	12	514	331	
9-19-63	--	8.0	705	103	18	13	3.0	0	204	45	96	12	0.3	0.03	14	562	330	
6-25-64	--	7.9	750	71	41	17	4.0	0	216	56	106	12	0.2	0.07	--	660	349	
8-18-64	--	7.8	760	69	44	19	5.0	0	224	52	110	13	0.2	0.07	--	844	355	
2-8-64	--	8.0	765	104	22	15	4.0	0	222	53	100	16	0.5	0.10	--	944	350	
2-4-65	--	7.9	740	68	49	17	4.0	0	228	54	111	15	0.2	0.07	--	534	370	
1/104-78K2																		
7-23-63	70	7.8	740	106	21	14	4.5	0	260	43	53	51	0.2	0.05	13	492	349	
8-18-64	--	7.5	860	89	47	17	5.0	0	292	58	58	106	0.1	0.10	--	568	417	
2-8-64	--	7.8	829	120	23	14	5.0	0	287	51	49	100	0.4	0.05	--	580	394	

TABLE 40 (cont.)

State well number	Temp when sampled in °F	pH	Specific conductance (micro-mhos at 25°C)	Mineral constituents in parts per million														TDS	Total Anions as CaCO ₃
				Calcium Ca	Magne- sium Mg	Sodium Na	Potas- sium K	Carbon- ate CO ₃	Bicar- bonate HCO ₃	Sulfate SO ₄	Chlo- ride Cl	Ni- trate NO ₃	Fluo- ride F	Boron B	Sili- ca SiO ₂				
Date sampled																			
1S/104-8A2																			
3-15-63	--	7.7	480	66	17	12	4.2	0	226	31	18	31	0.2	0.05	15	342	23		
7-23-63	70	7.8	490	62	17	13	4.0	0	217	20	18	31	0.2	0.05	14	302	22		
8-18-64	--	7.7	490	66	17	13	7.0	0	226	29	18	32	0.2	0.07	--	307	23		
12- 8-64	--	7.8	491	72	14	11	4.0	0	217	33	19	33	0.4	0.05	--	280	23		
1S/104-9F1																			
3-13-63	66	7.4	585	84	18	19	4.3	0	265	35	23	43	0.2	0.00	17	424	281		
7-24-63	70	7.7	630	88	13	19	4.0	0	250	38	23	48	0.2	0.05	17	400	271		
8-17-64	--	7.5	600	83	17	21	4.0	0	237	46	29	60	0.1	0.07	--	392	276		
12- 9-64	--	7.9	615	87	14	16	4.0	0	236	49	25	37	0.4	0.06	22	404	283		
8-31-65	68	8.2	619	87	16	18	4.0	0	232	55	26	48	0.3	0.06	--	375	283		
1S/104-9H2																			
3-13-63	66	7.5	550	75	17	22	2.4	0	244	44	16	60	0.4	0.00	20	396	260		
7-25-63	70	7.6	590	68	18	22	2.3	0	235	25	16	56	0.2	0.03	18	360	247		
8-13-64	--	7.7	530	87	7	24	2.0	0	225	46	18	50	0.4	0.12	--	368	245		
12- 9-65	--	8.0	563	73	15	20	2.0	0	232	38	15	49	0.6	0.03	27	367	245		
9- 1-65	69	7.7	583	73	16	20	2.0	0	229	38	20	59	0.5	0.02	--	346	249		
1S/104-10C1																			
3-13-63	66	7.6	540	78	16	19	3.6	0	229	54	13	50	0.2	0.00	23	402	259		
7-24-63	70	7.6	590	64	22	20	3.0	0	220	38	14	66	0.2	0.03	21	386	253		
9-19-63	68	7.7	526	74	13	17	2.3	0	231	37	12	43	0.3	0.05	23	352	236		
6-25-64	62	8.0	600	60	29	21	3.0	0	231	51	18	65	0.1	0.05	--	452	270		
8-12-64	--	7.4	590	83	16	22	3.0	0	225	54	19	64	0.2	0.10	--	406	274		
12- 7-64	--	7.7	586	73	19	18	3.0	0	219	50	15	39	0.4	0.04	28	382	259		
5- 4-65	65	7.9	570	70	23	21	3.0	0	220	51	22	59	0.1	0.06	--	376	271		
9- 1-65	69	8.3	602	73	20	19	3.0	11	195	46	21	74	0.4	0.02	--	382	266		
5-10-62	--	8.4	555	67	18		2.0	23	175	44	19	53	0.5	0.00	22	405	161		
7-24-63	70	7.7	530	54	21	22	2.3	0	207	33	11	56	0.2	0.03	20	336	223		
8-12-64	--	7.6	540	75	13	23	2.0	0	221	54	14	58	0.4	0.07	--	360	245		
12- 7-64	--	8.0	584	71	19	21	3.0	0	220	52	14	59	0.5	0.02	--	397	252		
9- 1-65	67	8.4	558	67	20	19	2.0	5	203	46	17	61	0.5	0.00	--	310	249		
1S/114-12H2																			
3-14-63	63	7.8	300	40	13	8	3	0	174	27	4	4	0.2	0.00	11	222	154		
7-26-63	67	7.8	330	45	8	9	3	0	178	13	4	4	0.2	0.06	11	182	148		
8-18-64	--	7.9	310	46	9	9	3	0	175	16	3	4	0.2	0.05	--	198	150		
12-11-64	--	7.7	359	51	9	9	3	0	161	22	8	8	0.4	0.05	--	180	164		
8-31-65	66	8.2	346	45	10	8	2	0	163	21	9	3	0.4	0.03	--	157	153		

TABLE 41

MINERAL ANALYSES OF GROUND WATERS AT THE MAYFLOWER WELL

State well number	Temp when sampled in °F	pH	Specific conductance (micro-mhos at 25°C)	Mineral constituents in parts per million														TDS	Total hardness as CaCO ₃
				Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO ₃	Bicarbonate HCO ₃	Sulfate SO ₄	Chloride Cl	Nitrate NO ₃	Fluoride F	Boron B	Silica SiO ₂				
14-1R1	--	7.2	--	44	24	--	--	0	226	22	26	--	0.3	--	--			271	210
16-54	--	7.7	--	61	17	11	--	0	198	17	24	40	0.3	0.4	--			210	210
30-58	--	7.0	--	76	20	15	2	0	206	36	22	--	0.3	--	--			272	238
4-59	--	7.1	--	65	16	16	2	0	192	24	17	--	0.4	--	--			344	238
18-59	--	7.5	--	62	17	16	2	0	225	21	15	--	0.4	--	--			344	225
1-59	--	7.7	--	76	22	17	2	0	225	12	23	--	0.5	--	--			390	260
15-59	--	7.7	--	72	21	16	2	0	204	26	19	--	0.4	--	--			425	264
28-59	--	7.5	--	84	23	18	2	0	215	28	24	--	0.3	--	--			485	305
24-59	--	7.3	--	84	23	18	2	0	216	--	14	25	--	--	--			251	199
29-59	--	8.3	415	54	13	--	--	0	206	30	24	--	0.2	--	--			439	310
20-59	--	7.8	--	80	24	17	2	0	205	28	23	--	0.3	--	--			439	295
11-59	--	7.6	--	80	23	17	2	0	222	18	14	0	--	--	--			370	255
14-59	--	7.7	400	52	15	12	--	0	199	26	18	--	0.3	--	--			365	240
7-59	--	7.5	--	66	22	16	2	0	175	23	16	--	0.4	0.0	--			315	262
25-59	--	7.5	--	62	21	14	2	0	239	26	18	64	0.3	--	--			435	236
26-60	62	7.5	563	70	21	16	2	0	204	31	22	--	0.4	0.3	--			370	295
24-60	--	7.6	--	79	22	16	2	0	205	31	25	14	0.4	--	--			383	240
26-60	--	7.3	--	79	24	13	2	0	190	16	17	9	0.4	--	--			345	230
11-60	--	7.5	--	69	18	12	2	0	181	26	17	7	0.3	--	--			273	194
10-61	--	7.6	--	64	17	16	2	0	166	19	14	4	0.4	--	--				
27-61	--	7.7	--	54	14	15	2	0											

TABLE 42

MINERAL ANALYSES OF GROUND WATERS - MAYFLOWER WELL AREA

State well number	Temp when sampled in °F	pH	Specific conductance (micro-mhos at 25°C)	Mineral constituents in parts per million														TDS	Total hardness as CaCO ₃
				Calcium Ca	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO ₃	Bicarbonate HCO ₃	Sulfate SO ₄	Chloride Cl	Nitrate NO ₃	Fluoride F	Boron B	Silica SiO ₂				
Date sampled																			
1N/10W-31M1																			
9-14-54	70	7.9	457	62	13	12	4	0	227	28	10	20	0.2	0.38	--		240	205	
12-23-59	--	7.6	535	68	15	11	3	0	243	25	8	30	0.3	0.03	23		---	205	
4-21-60	--	--	---	--	--	--	--	0	229	--	9	--	--	---	--		---	205	
3-22-62	--	7.5	329	45	10	9	3	0	170	15	10	7	0.4	0.00	15		250	155	
1N/11W-36R1																			
8-7-58	66	8.1	346	45	10	12	3	0	185	14	8	9	0.3	0.06	20		220	156	
4-21-60	--	8.0	418	55	11	14	3	0	207	19	14	15	0.3	0.00	17		236	181	
3-23-62	--	8.4	459	48	18	17	4	6	214	28	18	4	0.3	0.25	17		340	196	
1S/11W-2G1																			
11-7-58	63	7.4	668	86	29	21	2	0	310	30	28	73	0.1	0.04	25		430	334	
9-14-59	--	7.8	560	75	23	12	2	0	300	31	29	0	--	---	--		---	283	
4-18-60	--	7.7	585	74	18	16	2	0	258	54	20	0	0.3	0.04	20		403	261	
12-29-61	63	7.9	432	54	15	16	2	0	205	12	12	46	0.5	0.05	26		285	196	
1S/11W-2K4																			
5-6-58	72	7.5	508	64	18	14	4	0	184	62	20	35	--	---	--		---	234	
3-11-59	61	7.6	526	74	16	7	3	0	226	44	20	20	--	---	--		---	290	
4-28-60	--	8.0	598	81	18	14	2	0	257	57	22	24	0.3	0.00	15		445	278	
1S/11W-10F1																			
5-19-58	62	8.0	416	52	13	14	2	0	204	12	22	15	0.5	0.04	27		289	185	
12-22-60	64	8.1	---	66	11	14	2	0	220	27	14	29	0.3	0.08	17		348	210	
3-22-62	--	7.5	376	47	13	17	2	0	193	30	15	6	0.4	0.00	22		295	171	
1S/11W-10H1																			
6-1-59	64	7.7	650	82	20	38	2	0	375	19	21	19	0.3	0.06	25		384	268	
3-23-62	--	8.2	586	68	22	29	2	0	310	39	19	8	0.4	0.40	21		450	299	
1S/11W-10P1																			
7-9-59	--	7.9	381	48	12	13	2	0	197	10	16	8	0.4	0.00	23		287	172	
1S/11W-11F1																			
6-1-59	--	7.6	431	43	11	33	5	0	204	35	12	3	0.2	0.06*	28		257	153	
4-29-60	--	6.5	1,053	122	36	65	6	0	555	30	85	1	0.0	0.38	35		818	455	
1-10-61	--	7.0	309	35	9	14	2	0	146	20	9	4	0.2	0.16	25		170	122	
1S/11W-14M1																			
5-19-58	62	7.4	351	50	13	8	3	0	189	16	18	9	0.4	0.45	13		248	180	
4-18-60	--	8.1	413	57	12	9	2	0	199	16	14	22	0.3	0.04	12		310	191	
8-17-61	--	8.0	480	62	17	11	3	0	199	39	18	20	0.1	0.08	14		306	225	
5-9-62	--	7.7	495	68	16	9	3	0	207	36	14	39	0.4	0.02	15		261	235	
1S/11W-15L2																			
8-7-58	62	8.1	416	51	16	12	2	0	188	28	15	24	0.4	0.10	25		---	194	
4-18-60	--	7.6	523	66	17	15	4	0	211	31	20	37	0.3	0.02	20		303	235	

TABLE 43

MINERAL ANALYSES OF GROUND WATERS
AT TEST WELLS--AZUSA

State well number	Temp when sampled in °F	pH	Specific conductance (micro-mhos at 25°C)	Mineral constituents in parts per million													Total hardness as CaCO ₃
				Calcium Co	Magnesium Mg	Sodium Na	Potassium K	Carbonate CO ₃	Bicarbonate HCO ₃	Sulfate SO ₄	Chloride Cl	Nitrate NO ₃	Fluoride F	Boron B	Silica SiO ₂	TDS	
10W-401																	
2-19-62	60	8.0	345	41	9	15	3.7	0	120	35	14	30	0.2	0.08	22	234	139
3-12-63	66	7.6	456	62	12	12	3.5	0	215	22	14	17	0.3	0.12	15	200	201
5-6-63	66	7.7	420	63	12	12	4.2	0	223	29	13	16	0.1	0.07	13	310	206
7-8-64	67	7.7	510	64	17	12	4.1	0	228	23	16	23	0.2	0.09	17	306	228
9-25-63	67	7.6	460	31	32	13	3.6	0	226	17	9	21	0.2	0.08	16	278	206
2-14-64	66	7.5	464	66	13	14	4.2	0	235	20	12	23	0.3	0.11	30	274	219
7-8-64	66	7.9	460	63	13	12	3.5	0	226	21	9	19	0.2	0.06	16	260	221
8-10-64	---	8.0	460	60	16	14	3.0	0	224	24	14	26	0.2	0.05	---	284	215
9-11-64	---	8.1	480	99	15	14	4.0	0	227	19	14	22	0.2	0.07	---	298	208
2-9-64	---	8.1	380	49	10	13	4.0	0	163	25	13	28	0.2	0.10	---	210	161
1-19-65	---	7.7	440	41	22	14	4.0	0	198	19	16	22	0.2	0.07	---	356	197
3-30-65	---	7.9	468	67	12	12	4.0	0	222	22	12	28	0.4	0.06	21	300	215
5-10-65	---	8.2	470	55	23	15	3.0	0	232	29	19	23	0.2	0.19	---	302	231
5-26-65	68	7.6	450	53	19	14	4.0	0	222	15	18	22	0.2	0.12	---	298	212
	67	7.7	450	67	11	13	3.0	0	214	16	20	24	0.2	0.11	---	292	214
	68	7.5	443	58	13	12	4.0	0	217	21	10	19	0.3	0.08	---	250	198
113W-302																	
2-19-63	---	7.6	522	75	12	13	4.0	0	232	23	20	32	0.4	0.06	21	305	236
3-12-63	66	7.7	500	80	11	13	3.6	0	253	22	20	27	0.2	0.05	16	354	243
5-6-63	67	7.7	450	56	17	13	4.0	0	216	24	11	20	0.2	0.00	17	276	207
7-8-64	67	7.7	530	50	27	13	3.7	0	235	21	18	31	0.2	0.08	16	314	235
9-24-63	---	7.5	534	75	15	13	3.8	0	234	20	20	35	0.4	0.06	21	327	247
2-14-64	66	8.0	500	70	13	14	3.5	0	229	24	16	29	0.2	0.06	15	320	230
7-8-64	---	7.8	505	70	15	13	3.0	0	242	24	15	31	0.2	0.10	---	318	217
8-10-64	---	8.0	500	51	27	14	4.0	0	230	25	15	26	0.2	0.09	---	316	236
9-11-64	---	8.2	520	59	23	13	3.0	0	235	27	16	30	0.4	0.12	---	338	240
10-8-64	---	7.7	500	47	24	15	4.0	0	212	22	21	26	0.2	0.10	---	346	217
12-8-64	---	7.5	532	76	12	13	4.0	0	234	23	20	37	0.4	0.07	---	280	239
1-20-65	---	8.1	480	57	23	13	4.0	0	215	31	20	32	0.2	0.12	---	310	235
3-30-65	68	8.0	440	65	12	8	1.0	0	214	19	15	24	0.4	0.09	---	304	215
5-10-65	68	7.7	480	69	15	14	3.0	0	237	23	21	26	0.2	0.11	---	290	231
5-26-65	68	7.6	496	70	12	12	4.0	0	229	20	14	25	0.4	0.06	---	286	224
10W-401																	
3-12-63	66	7.8	420	60	11	18	5.4	0	220	39	16	6.0	0.2	0.12	11	294	195
5-6-63	70	7.7	420	53	12	15	3.7	0	199	29	13	3.6	0.2	0.17	14	246	185
7-8-64	67	7.7	480	63	10	16	4.1	0	216	32	13	7.6	0.2	0.13	15	260	198
9-25-63	---	7.8	393	46	12	16	4.5	0	168	31	17	7.8	0.4	0.14	28	298	164
2-14-64	68	8.0	440	69	6	18	4.0	0	215	35	14	8.3	0.1	0.25	13	282	197
7-8-64	---	7.8	455	61	11	19	4.0	0	222	30	18	9.0	0.1	0.15	---	270	197
8-10-64	---	8.1	450	42	24	20	4.0	0	233	31	14	4.0	0.2	0.16	---	266	205
2-9-64	---	7.4	460	53	16	20	4.0	0	211	28	20	8.0	0.2	0.02	---	300	195
3-30-65	68	7.2	510	73	11	22	4.0	0	279	13	28	5	0.2	0.17	---	304	229
5-10-65	68	7.1	541	69	16	19	5.0	0	283	19	14	10	0.3	0.14	---	310	238





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